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GLUE-COMPOSITE JOINTS IN TECHNOLOGY

by

V. N. Shavyrin, N. Kh. Andreyev and
A. A. Itskovich

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GLUE-COMPOSITE JOINTS IN TECHOLOGY

By: V. N. Shavyrin, N. Kh. Andreyev, and
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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

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* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

Glue-Composite Joints in Technology, V. N. Shavyrin, N. Kh. Andreyev, A. A. Itskokovich, "Machine Building." 1968. 230 p.

In the book a new progressive method is described for joining structural elements made from aluminum alloys – producing composite, permanent glue-welded, glue-riveted, and glue-threaded joints, distinguished by high strength (especially under cyclical loads), longevity, airtightness, and good corrosion resistance.

In the book there are given the basic physical and mechanical and technological characteristics of constructional glues, recommendations for selection of grade of glue and rational technology for its use in concrete combined joints. Strength characteristics are given for welded, glue-welded, glue-riveted and glue-threaded joints, allowing a comparison of efficiency of various forms of joints and selection of optimum technology in their manufacture. There are provided short recommendations in regard to designing of thin-sheet constructions, prepared with the use of glue-welded, glue-riveted and glue-threaded connections, and also their technical-economic effectiveness.

The book is intended for a wide circle of technologists, designers, and scientists in various branches of technology.

Tables 97. Illustrations 69. Bibliography. 45 titles.

Reviewed by Candidate of Technical Sciences Yu. V. Dmitriyev

INTRODUCTION

Composite glue-welded, glue-riveted and glue-threaded joints – a comparatively new type of permanent joints which have only recently obtained industrial application. The necessity for development of new methods of creating permanent joints appeared as a result of the continuous increase in requirements imposed on modern important articles, and because of the imperfection of riveted joints which are the most widespread in machine-building constructions.

An essential deficiency of riveted joints – the necessity for drilling holes in the elements being joined; this reduces cyclical strength, corrosion resistance, and operational longevity. Furthermore, riveting is low in productivity and costly; in working with pneumatic percussion hammers the workers develop professional sicknesses – deafness and vibration sickness.

Welded and glued joints constructively are similar to riveted but are more rational and progressive. Joints carried out point and seam welding in strength and reliability are hardly inferior to riveted, have less weight, and in respect to degree of automation and productivity of the process of manufacturing noticeably surpass them. Welding lightens the labor condition of the workers. However, cyclical strength and especially corrosion resistance of welded joints made from aluminum alloys are insufficient for important articles. Therefore, in spite of the presence of completely modern, highly productive equipment, welding of constructions from Duralumin did not find wide industrial acceptance.

Glued articles have a number of essential advantages over welded and riveted: they are airtight, have high cyclical strength, and good corrosion resistance. With gluing it is possible to join heterogeneous metals and metals with nonmetals. However glued connections poorly withstand combined action of bending and tearing loads (nonuniform breaking). For production of high-quality joints there is required rather high uniform pressure and general or local heating of the parts. Thus, for large dimension structures complex, bulky and expensive equipment is required (presses, autoclaves, and so forth).

Thus, neither riveted nor welded nor glued connections individually can satisfy the increased requirements for strength and reliability of constructions. In composite glue-welded, glue-riveted, and glue-threaded joints, obtained as a result of a combination of technological processes, for example, spot welding or riveting and gluing of metals maximum use is made of the advantages of welding or riveting and gluing and many of the deficiencies inherent to each of these processes separately are excluded.

Chemically stable glues ensure reliable anticorrosive protection of the internal cavity of overlap and simultaneously hermetically seal the joint cavity. The gluing layer absorbs a considerable part of tensions during loading of the composite joint, unloading the welded point, the rivet or bolt (screw), and improving their efficiency. Redistribution of tensions considerably decreases their concentration in a dangerous section, which considerably increases the strength of the composite joint, especially under cyclical loads. In turn, the welded points, rivets, or bolts improve the work of the glued seam under conditions of nonuniform breakaway, thereby increasing the total efficiency of the construction.

Thanks to the mentioned advantages of composite joints, interest in them continuously increases. At present in domestic literature, questions on technology of manufacture and properties of composite joints are elucidated extremely insufficiently. In this book an

attempt is made to at least partially close this gap. The quality of composite constructions, in many respects, depends on the physical and mechanical and technological characteristics of the glues employed. Therefore, in this book considerable attention is devoted to description of the properties of domestic glues.

The most important criteria for appraisal of the quality of a joint are its strength characteristics. Questions of strength, technology, and properties of materials during the production of composite joints are intimately connected with one another. Therefore, in this book much attention is devoted to consideration of the strength of joints during different forms of loads. The characteristics provided will enable selecting the optimum technology and design parameters of composite joints, and also enable comparing the efficiency of different forms of joints.

The authors will be grateful to the readers for critical remarks, requests and opinions, which should be directed to: Moscow, B-66, 1 - Basmannyy Pereulok., 3, publishing house "Machine Building."

CHAPTER I

GLUES FOR GLUE-COMPOSITE JOINTS

At present there are more than 100 different domestic glues, created on the basis of synthetic and natural resins modified by fillers and other additives [11]. A considerable part of these glues is intended basically for gluing of metals [14].

For production of high-quality glued joints it is necessary to have rather high external pressure evenly applied over the whole area of overlap (sometimes attaining 20 kgf/mm^2) and general or local technological heating of the parts. A feature in the production of glue-welded joints consists in the fact that it is impossible to create specific pressure on the glue layer during its hardening. In these joints hardening of the glue layer occurs without the application of specific pressure.

Confirmation of this is derived from the fact that the strength indices of glue-welded joints carried out with application of epoxy glues well filling the clearances of (FL 4S, VK 1, VK 1MS and others), turn out to be practically identical both with welding by a layer of glue, and also during introduction of glue into the joint cavity after welding, when external pressure is completely removed. Joints with a layer of liquid glue (VK 32-200, VK 32-250, BF 2, and others), which require high specific pressure for hardening have low strength indices.

Glues intended for gluing of metals, must meet the following requirements: 1) be corrosionally inactive with respect to the given metal or alloy; 2) have good adhesion with the metal and the alloy; 3) must harden under slight specific pressure where deflection in the amount of pressure will not essentially affect the strength of the glue layer obtained; 4) be comparatively cheap, possess very prolonged service life, and also sufficient viability to polymerization and elasticity after hardening; 5) possess high penetrating ability, climatic stability, stability during aging and against fungi, bacteria, and so forth; 6) be slightly sensitive to sharp variations in temperature and atmospheric humidity, and also be nontoxic; 7) possess, in a number of cases, (proceeding from conditions of use) sufficient heat resistantness in a defined interval, to temperature, frost-resistance, and also stability in water, against various fuel substances and oils, antifreezes, organic solvents, and other special media.

On glue intended for the manufacture of composite joints – glue-welded, glue-riveted, glue-threaded and glue-bolted – there are imposed additional requirements: 1) sufficient fluidity and good filling of cavity clearances of the connections mentioned; 2) possibility of welding by a damp layer during the full cycle of manufacture of a structural element without the glue running out during polymerization; 3) airtightness of connections, creation of shielding against penetration of the electrolyte in their clearances during anodizing; 4) ability to harden under minimum (desirably by contact) pressure and low temperature; 5) low sensitivity to thickness of the glue layer and comparatively great lengthening of it in the joint.

The majority of standard glues used for gluing of metals can be used only for the production of riveted or glue-threaded joints and are quite unfit for production of glue-welded joints. In connection with this there arose the necessity to search for and develop new specialized glue compositions intended mainly for the production of glue-welded joints.

Data on the physical and mechanical and technological properties of a number of domestic standard and specialized glues have been obtained by the authors as a result of analysis and generalization of literary sources and experimental investigations conducted for the purpose of establishing the possibility of using these glues in the production of glued composite joints. The authors have not raised the problem of discussing questions on the classification of glues since they have been examined in sufficient detail in special literature [11, 12].

Depending upon ability to work under certain temperature conditions, all the glues examined below are conditionally divided into two groups: 1) general purpose glues – glues capable of prolonged work during heating up to 60-80°C; 2) heat-resistant glues, capable of prolonged or short-term work during heating up to 150-350°C and higher.

Depending upon the temperature of gluing, the examined glues are also divided into two groups: 1) self setting glues – glues which do not require technological preheating for hardening, since by introducing special solidifiers and catalysts into them, chemical reactions proceed rapidly; 2) thermo (warm) setting glues – glues which during gluing require technological preheating approximately to 150-250°C.

General Purpose Glues

Glues BF 2 and BF 4 consist of alcohol solutions of phenol-formaldehyde resin combined with polyvinylbutyral. They are the most widely used of all the BF series glues and are intended for gluing of metals, plastics (especially structural) and ceramics. For gluing thermoplasts BF 4 glue is recommended.

Formulas of glues (parts by weight) [11]:

	BF 2	BF 4
Resol..........................	1	1
Polyvinylbutyral................	1	5.7

Both glues are resistant to the action of gasoline, alcohol, and oils, and possess satisfactory water-resistance. Joints made with glue BF 4 are less water-resistant than those with glue BF 2. They cause pitting of steel and have limited thermal stability. At 60°C there is even observed a sharp reduction in the shearing strength τ_B of joints and in uniform breakaway (Table 1). Conditions of gluing, for example for glue BF 2, are the following: temperature of preheating of the article 140-160°C; holding 0.5-1.0 h; pressure 2-10 kgf/cm^2.

Table 1. Shear strength τ_B per kgf/cm^2 of joints made with liquid glue BF 2.

Material	Temperature of test in °C			At 20°C after the action of		
	-60	20	60	Temperature ±60°C, 60 cycles	moist air (98%) for 30 days	water for 30 days
Duralumin D16AT anodized with dichromate filling.................	90	220	110	220	220	200
Steel 30KhGSA sand-blasted...........	130	370	150	370	370	350

Both glues can be used both in liquid form and also in the form of films of different thickness. In liquid form they possess low fluidity during molding and fill the clearances poorly. In film form, the glues are more liquid and fill the clearances better.

Elasticity and heat resistance of BF series glues are determined by the Butvar content in them. With an increase in the content of the latter the elasticity of the glues is increased, but heat resistance decreases. The BF glue contains considerably more Butvar than BF 2 glue, and therefore ensures greater elasticity of joints and somewhat less heat resistance.

Uniform breaking strength of joints, made with BF 2 glue at $20^{\circ}C$ equals 300-500 kgf/cm^2, and with nonuniform only 28 kgf/cm. Tensile strength of joints carried out on BF 4 film glue in nonuniform breakaway is considerably higher and equals 30-60 kgf/cm. However during prolonged heating of the joints made with BF 2 and BF 4 glues age comparatively rapidly which causes their embrittlement and considerable lowering of their nonuniform breaking strength.

Connections made with BF 2 glue possess comparatively low stress rupture strength, especially during heating, and low fatigue strength. Thus, stress rupture strength during shift at $20^{\circ}C$ equals 62 kgf/cm^2 (2000 h base), and at $60^{\circ}C$, 13 kgf/cm^2 (300 h base). Fatigue-strength during shift at $20^{\circ}C$ is equal to 26 kgf/cm^2 on a base of $6 \cdot 10^6$ cycles [14].

In connection with lowered fluidity and ability to fill the clearances; and the necessity for creation of high specific pressures on glue layer during hardening of the glue, and also the high cost of glues BF 2 and BF 4 liquid glues they cannot be recommended for production of glue-welded joints. According to experiments conducted by R. B. Goryunov, these glues are rationally used in the form of a film reinforced by a caproic web for glue-riveted joints.

Glue MPF 1 consists of an alcohol solution methylolpolyamide resin PFE 2/10, inoculated with grade A bakelite varnish. It hardens during heating ($155^{\circ}C$ for 1 h), is nontoxic, can be used in liquid form and in the form of films in the manufacture of aluminum, magnesium, and steel power constructions, and also for gluing of metals with fiberglass laminates in articles working in a range of temperatures of $\pm 60^{\circ}C$. In [14] following rational gluing technology is recommended: prepare by mixing a solution of methylolpolyamide with phenolformaldehyde resin, apply the glue composition in liquid form on surfaces to be glued, dry, then apply the film obtained from the liquid glue, collect and press article under pressure of 1-5 kgf/cm^2 and gluing temperature of $155^{\circ}C \pm 5^{\circ}$ for 1 h.

In liquid form, MPF 1 glue possesses good fluidity during molding and ability to fill clearances. Joints carried out on this glue possess considerable strength and high elasticity (Tables 2 and 3). However during prolonged direct action of a water medium, transformer oil, and alcohol the strength of these joints drops noticeably.

Table 2. Shear strength during shift $\tau_в$ in kgf/cm^2 of joints made with MPF 1 glue [14].

Material	Temperature of test in °C			
	−60	20	60	100
Duralumin D16AT anodized with dichromate filler....	130	200	90	60
Steel 30KhGSA sand blasted.....................	—	250	100	—
Magnesium alloy, oxidized......................	—	150	90	—

Table 3. Uniform strengths σ_{om} in kgf/cm^2) and nonuniform strength (S_{om} in kgf/cm) of Duralumin joints (anodized) made with MPF 1 glue.

Strength	Temperature of test in °C		
	−60	20	60
σ_{om}	450	300	150
S_{om}	40	65	40

A distinctive characteristic of MPF 1 glue is the fact that it ensures production of glued joints possessing the greatest resistance to nonuniform breaking as compared to other existing glued joints. Metal joints made with this glue also possess high stress rupture strength at temperatures up to 60°C and sustain vibration loads well. Thus, joints of Duralumin on MPF 1 glue are able, for example, to sustain for 160 h, without criteria of destruction, shear stress of 120 kgf/cm^2. Fatigue-strength during shear of a Duralumin joint at 20°C is equal to 55 kgf/cm^2 (on a base of $1.9 \cdot 10^6$ cycles) and at 60°C, 45 kgf/cm^2 (on a base of $0.8 \cdot 10^6$ cycles) [14].

Attempts to use MPF 1 glue for production of glue-welded joints did not give positive results. In spite of good fluidity, this glue did not ensure uniform filling of the cavity of overlap and is poorly pressed from contact site even in the case of application of considerable force of preliminary pressing. As a result of this, the process of welding is accompanied by separate splashes. Furthermore, the presence in this glue of a relatively large quantity of volatile solvents leads to the formation of considerable shrinkage, porosity, and bubbling in the glue layer of the joint disturbing its continuity. The MPF 1 glue also possesses poor penetrating ability, which greatly hampers production of glue-welded joints according to the "capillary" method of introduction of glue into the overlap clearance. The deficiencies noted, and also the low moisture resistance of this glue does not permit recommending it for the production of glue-welded joints.

However, as experiments show, MPF 1 glue, possessing considerable strength and especially high elasticity can be used for the production of glue-riveted and glue-threaded joints. In so doing, the edges of the joints must be protected from incidence of moisture by varnish and paint coatings.

Glue FL 4 consists of an alcohol-acetone solution of thermosetting combined furyl resins; nontoxic (140-160°C); period of storage more than 6 months; heat resistant up to 60°C; it is prepared from waste of agricultural production, therefore it is the cheapest of the existing synthetic glues. The glue possesses high fluidity and ability to fill clearances during gluing. It has good adhesion to metals and many plastics, and simultaneously with this, possesses anticorrosive protective properties. Therefore it is designed basically for gluing of aluminum and steel parts with certain nonmetallic materials, and also for use as protective coverings on parts working in corrosionally-active media. Tensile strength during shift of glued joints of Duralumin D16 at 20°C equals 130-140 kgf/cm^2.

The FL 4 glue is resistant to the action of liquid fuels, alkalis, acid and water media, and also electrolytes used during anode oxidizing. However, the glue layer after hardening possesses insufficient density, for which reason the internal cavity of the joint, in a number of cases, is penerated by the electrolyte [10, 13]. This is caused by the fact that in the process of polymerization of a glue containing a large quantity of solvent (dry residue does not exceed 25%), during evaporation of the solvent in the glue layer there will be formed bubbles and gas pockets. The latter, disturbing the continuity of this layer, are areas for penetration of the electrolyte. By means of application of proper preparation of the surfaces to be glued and a certain step graph of heat treatment of glued connections it is possible to partially decrease the formation of the noted defects and, consequently, to increase the airtightness of the glued seam.

The FL 4 glue, possessing satisfactory technological properties can be recommended for the manufacture noncritical glue-welded constructions made from aluminum alloys. However, in so doing, it must be considered that it does not ensure sufficiently reliable airtightness of the joints.

Glue KS 609[1] is a composition consisting of a solution of butylmethacrylate in a monomer, a hardener and a filler. In chemical nature it is a typical thermoplastic material with softening temperature of 80°C and has the following composition [3, 17]: 40 parts by weight of the polymer butylmethacrylate; 60 parts by weight of butylmethacrylate monomer; 0.5 parts by weight of dimethylaniline (hardener) and 50-100 parts by weight of quartz electrode powder (filler). The filler and hardener are introduced into the prepared base directly before using the glue.

The KS 609 glue hardens at room temperature and is nontoxic. It is designed mainly for the production of glue-welded joints and has found application in shipbuilding production and other constructions [3, 8]. However this glue can also be successfully used for

production of glue-riveted joints and also for gluing of parts made of aluminum and steel.

The KS 609 glue possesses especially high plasticity in hardened state, which is especially important for joints working under cyclical loads, and on nonuniform breakaway. For example, plates with deposited and hardened glue can be bent repeatedly 180° without damage to the continuity of the glue layer. Here one should note that the glue can preserve high elasticity for a very prolonged time (for a number of years), which indicates that it is not inclined to age at room temperature. This important property is explained by the fact that in the composition of the glue a plasticizer is absent, the presence of which usually facilitates the aging of glue compositions.

In Tables 4 and 5 indices are given for the strength of joints of Duralumin and steel made with KS 609 glue. Shear and uniform breaking strength of joints using this glue, is comparatively low, therefore it is characterized as a constructional glue of low strength. However, in connection with its ability to harden at room temperature and to give dense and highly-plastic joints KS 609 glue presents considerable practical interest.

Inasmuch as KS 609 glue is self-setting the strength of the glue layer in the joint is changed with passage of time. From Tables 4 and 5 it is clear that the glue obtains considerable strength even after the expiration of 3-4 days from the moment of its manufacture, and maximum strength - after 7 days. However the polymerization process of this glue takes place intensively, and even after 3 hours after manufacture the tensile strength of the glued joint becomes very considerable. The state of surface (Table 4) renders an essential effect on the strength of the gluing. Thus, anodizing leads to a considerable reduction of shear strength. Here the color of the anodized layer changes from light-yellow to different shades of blue.

Table 4. Shear strength $\tau_{в}$ in kgf/cm^2 of joints made with KS 609 glue depending upon duration of hardening.

Material	Duration of hardening in twenty-four hours periods.			
	3	4	5	6
Duralumin D16T anodized with filler by dichromate......................	31 / 27,1—35,6	58 / 41—65	33 / 17—42	28 / 17—38
Duralumin D16T, cleaned with a steel brush.............................	69 / 64—76	74 / 71—75	69 / 62—72	74 / 66—69
Steel 30KhGSA, sand blasted..........	67 / 61,3—71	—	—	—

Material	Duration of hardening in days			
	7	8	10	13
Duralumin D16T anodized with filler by dichromate......................	41 / 18—53	26 / 24—27	35 / 24—46	39 / 34—43
Duralumin D16T, cleaned with a steel brush.............................	74 / 64—83	72 / 60—78	69 / 53—75	75 / 53—84
Steel 30KhGSA, sand blasted..........	77,4 / 67,8—83,2	—	78,4 / 66,5—86,7	—

Table 5. Uniform breaking strength σ_{om} in kgf/cm^2 of joints made with KS 609 glue depending upon duration of hardening.

Material	Duration of hardening in days				
	3	7	10	30	180
Duralumin D16T, cleaned with a steel brush...............	50 / 46,5—52,5	47 / 42,5—50	51 / 44—54	42 / 41—57	60,8 / 48,2—72,5
Steel 30KhGSA, sand blasted..	42 / 38—48	42 / 33—67	47 / 42—54	47 / 39—57	61,3 / 48,2—72,5

The cause of this phenomenon is not clarified, it is possible only to assume chemical influence of one of the components of KS 609 glue with chromium compounds in pores of the anode film.

In Table 6 results are given of standard static tests for heat resistance and frost resistance of joints made with KS 609 glue. Holding time of the samples at rated temperature amounted to 30 minutes. As can be seen, the strength of joints drops sharply during heating to 60-80°C, which testifies to the low heat resistance of KS 609 glue. However, heating of glued joints at these temperatures with subsequent tests at room temperature does not lead to a change in their strength (Table 7).

Table 6. Shear strength $\tau_в$ and uniform breaking strength σ_{om} in kgf/cm^2 of joints made with KS 609 glue under different temperature conditions.

Temperature of test in °C	Duralumin D16T, cleaned with a steel brush		Steel 30KhGS, sand blasted	
	$\tau_в$	σ_{om}	$\tau_в$	σ_{om}
−60	$\frac{58}{49--63}$	—	—	—
−20	$\frac{81,3}{65,8-92,5}$	$\frac{102,6}{90,5-108,8}$	$\frac{103,1}{67-135}$	$\frac{118,2}{104,8-126,7}$
−10	$\frac{88,2}{74,0-98,5}$	$\frac{79}{65,8-98,5}$	$\frac{109}{78,5-133}$	$\frac{117}{110-128,5}$
+20	$\frac{60,8}{59,4-62,9}$	$\frac{53,6}{46,5-62}$	$\frac{60,5}{57,1-67,2}$	$\frac{53,5}{47,3-65,3}$
+60	$\frac{31,7}{27,5-36,5}$	—	—	—
+80	$\frac{3,7}{3,42-4,16}$	$\frac{6,01}{4,85-8,9}$	$\frac{6,7}{5,72-8,15}$	$\frac{8}{7,85-8,5}$

The KS 609 glue posuess good water-resistance, and also resistance to the media used with chrome- and sulfuric acid oxidizing and phosphating. Thus, for example $\tau_в$ (kgf/cm^2) of glued joints after holding in salt and fresh water 30 days has hardly changed:

Control samples	Sea water	Fresh water
76.4 / 72.75—76.3	70.5 / 60.5—75	73 / 68.8—73

Table 7. Shear strength $\tau_{в}$ and uniform breaking strength $\sigma_{сж}$ in kgf/cm^2 of joints made with KS 609 glue heated to 80°C and then tested at 20°C.

Duralumin D16, cleaned with a steel brush	$\tau_{в}$	$\sigma_{ом}$
Control samples	65.5 / 59.5—61	55.2 / 49.0—59.8
After 100 h heating at 80°C	75.9 / 73.7—80.5	57.3 / 55.2—59.3

However, the resistance of this glue in fuel media (especially in kerosene) is insufficient (Table 8), therefore the use of joints made with KS 609 glue in vessels intended for fuel storage is inexpedient.

Table 8. Shear strength $\tau_{в}$ and uniform breaking strength σ_{om} in kgf/cm^2 of joints made with KS 609 glue after action of certain media on them during 30 twenty-four periods.

Medium	$\tau_{в}$		σ_{om}	
	Steel 30KhGSA, sand blasted	Duralumin D16T, cleaned with a brush	Steel 30KhGSA, sand blasted	Duralumin D16T, cleaned with a brush
Air (control)	59.3 / 52.7—58	58.5 / 55.7—60	53.5 / 47.3—65.3	53.6 / 46.5—62
Kerosene	29.9 / 24.2—39.2	34.4 / 23.6—49.7	28.8 / 20.5—44	23.4 / 11.5—35.8
Special fuel	55 / 46.6—62.5	44.6 / 12.8—65.9	50.2 / 47.2—52	46 / 40—55

Glues PU 2 and VK 5 are polyurethanes and consist of a composition on the basis of a polyester and hardener with a filler – with cement and without filler. They are intended for gluing of different metals and nonmetallic materials. Both glues permit thermo- and self-setting. However during heating of these glues, the hardening process takes place considerably faster than without heating. Furthermore, preheating ensures better quality of glued joints. These glues possess good fluidity at the time of pressing and ability to fill the clearances.

The PU 2 glue consists of a solution of polyfunctional polyester containing free hydroxyl and carboxyl groups, and products 24 (200 parts by weight) and 102T (100 parts by weight). Product 24 – a wax-like polyester which is used in the form of 50% solution in acetone. Product 102T – a polyisocyanite – is toxic. As a filler, Portland cement 400 is introduced into the glue somewhat lowering its water-resistance. Viability of the glue is about 2 h. It can also be used without filler.

The presence of polar groups in a molecule of polymer conditions high adhesion of PU 2 glue to different metals and nonmetallic materials. It is similar to epoxy glue and has 100% dry residue, possesses very small shrinkage during hardening and high ability to fill clearances. Furthermore, the glue is sufficiently elastic, is frost-resistant, but has lower water-resistance, therefore requires protection by varnish and paint coatings. Thus, the prolonged effect of water and humid air lowers strength of joints 30-40%.

In case of gluing with preheating at $105^{\circ}C \pm 5^{\circ}$ and pressure of 3 kgf/cm^2, duration of holding of glued Duralumin joints composes 4 h. Gluing at $20^{\circ}C$ is produced under pressure of 0.5-3 kgf/cm^2; in so doing, the strength of the glued joint gradually grows attaining maximum values (170-180 kgf/cm^2 shear strength) after 20-30 twenty-four hour periods. After twenty-four hours it comprises 25 kgf/cm^2 and 3 days – 120 kgf/cm^2 [11].

Shear strength and uniform breaking strength of joints made with PU 2 glue is rather considerable (Table 9) and is comparable with the strength of joints made with BF, MPF 1, and other glues. Joints made with PU 2 glue also possess good efficiency during nonuniform breaking: at 20°C, 43 kgf/cm, at 60°C, 21 kgf/cm.

Table 9. Shear strength τ_B in kgf/cm² of joints made with glue PU 2.

Material	Temperature of of test in °C			After the temperature ±60°C, 60 cycles
	−60	20	60	
Duralumin D16T, anodized with dicromate filling	140	180	160	180
Steel, 30KhGSA, sand blasted	230	280	210	280

Uniform breaking strength σ_{om} in kgf/cm² of joints of Duralumin D16 made with PU 2 glue is as follows:

Temperature of test in °C	−60	20	60	100
σ_{om}	400	300	160	60

Stress rupture strength of joints made with PU 2 glue and their endurance are fully satisfactory which is testified to by their comparatively slow aging during heating. Thus, fatigue-strength during shear of joints of Duralumin D16T at 20°C equals 40 kgf/cm², at 60°C, 15 kgf/cm², at 100°C, 10 kgf/cm²; joints of stainless steel Kh18N10T at 20°C, 79 kgf/cm², at 60°C, 55 kgf/cm², at 100°C, 30 kgf/cm².

Stress rupture strength of joints of Duralumin D16T made with PU 2 glue at 20°C equals 115 kgf/cm² (base of 1500 h), at 60°C 65 kgf/cm² (base 300 h), at 80°C 15 kgf/cm² (base 300 h); joints of steel Kh18N10T at 20°C 160 kgf/cm² (base 1500 h), at 60°C 110 kgf/cm² (base 300 h), at 80°C 80 kgf/cm² (base 300 h) and at 120°C 20 kgf/cm² (base 100 h).

In the process of prolonged stay in atmospheric conditions joints made with PU 2 glue are subject to aging, which causes noticeable lowering of their strength. For glue without filler, lowering of strength occurs to a lesser degree.

The PU 2 glue is resistant to prolonged action of petroleum fuels, oils, and alcohol-glycerine mixture. Specific resilience during shear of glued joints, for example Duralumin, at 20°C equals 5.5 kgf cm/cm^2, at 150°C 9.3 kgf cm/cm^2. Inasmuch as PU 2 glue is toxic, during work with it general and local ventilation are necessary, and also the observance of other measures in respect to safety engineering.

The VK 5 glue is prepared from the following four components: product 24, 1 part by weight; product DGU 1.07 parts by weight, product KSMK 0.001 parts by weight, acetone 2.07 parts by weight [14].

The VK 5 glue is considerably less toxic and is also more water-resistant than PU 2 glue, but possesses lower short-term and stress rupture strength, especially during heating up to 60°C. Thus, shear strength of joints of anodized Duralumin D16T, glued at 20°C with holding under pressure for 3 days, equals at 20°C 90 kgf/cm^2, at 60°C, 25 kgf/cm^2; joints of steel 30KhGSA, cleaned with sandpaper, at 20°C, 157 kgf/cm^2; at 60°C, 25 kgf/cm^2. When gluing with preheating, strength of the same joints is increased 10-15%.

Joints made with VK 5 glue possess comparatively low fatigue life to breaking. Thus, the uniform breaking strength of joints of plated nonanodized Duralumin D16AT equals at 20°C 217 kgf/cm^2, at 60°C, 50 kgf/cm^2; nonuniform breaking strength at 20°C, 24 kgf/cm; at 60°C, 15 kgf/cm.

Joints of plated anodized Duralumin made with VK 5 glue are resistant to the action of water for 30 days. Gluing with VK 5 glue with preheating is produced at a temperature of 110°C ± 5° under pressure of 0.5-3 kgf/cm^2 for 3-4 h.

Testing of PU 2 and VK 5 glues in production of glue-welded joints showed that in the case of welding by a layer of glue, in spite of relatively low viscosity, the glues are poorly pressed from the contact site and therefore do not permit selecting optimum conditions of welding. Besides this, the process of welding by glue is accompanied by very strong emanation of harmful toxic gases appearing as a result of combustion of glue not pressed completely from the welding contact, and also by overheating of glue adjoining the welded point. Introduction of the glues mentioned into the clearance of the joint after welding turned out to be impossible due to their low penetrating ability.

The noted deficiencies do not permit recommending PU 2 and VK 5 glues for production of glue-welded joints. However, as experiments showed, (see Chapters V and VI), PU 2 and VK 5 glues, possessing valuable mechanical and technological properties can be recommended for production of glue-riveted and glue-threaded joints inasmuch as in this case the glue layer does not undergo essential heating, and therefore intensive release of harmful gases is eliminated.

Glue FRAM 30 consists of a phenol-rubber composition, the basis of which is a block – a copolymer of phenolresorcinol resin and rubber containing fluorine. In composition, the glue includes: FRAM 30, resin 100 parts by weight, and a accelerator, 3 parts by weight. The glue composition is prepared from a calculation of its use of over a period of 6 h. The glue is intended for gluing of metals and nonmetals. It possesses reduced fluidity and penetrating ability, therefore fills clearances poorly during gluing.

The glue seam hardens at a temperature of 160-180°C under a pressure of 8-20 kgf/cm^2 in a period of 3-1 h [14]. A distinctive property of joints carried out with FRAM glue is very high elasticity. They can work under heating up to 80-100 C.

FRAM 30 glue can be used in liquid and film form. Film glue fills clearances somewhat better. However, the shear strength of joints thus is somewhat lower than the strength of similar joints carried out with liquid glue.

As can be seen from Table 10, joints made with FRAM 30 glue possess rather high shear strength and especially breaking strength both at 20°C and also during heating to 100°C. In respect to uniform breaking strength at 20°C the given joints exceed all other glued joints, and in resistance to nonuniform breaking hardly yield to the most highly durable joints made with MPF 1 glue under these loads (see Table 3). This testifies to the high elasticity of the FRAM 30 glue seam in hardened state. Along with this, joints made with FRAM 30 glue possess very high heat resistance. The latter shows that the given glue is very stable against heat aging. Thus, shear strength of Duralumin joints made with this glue, after the effect of a temperature of 80°C for 1000 h equals 250 kgf/cm², i.e., remains the same as at 20°C. The glue possesses satisfactory water-resistance.

Table 10. Strength of Duralumin D16AT (anodized) joints made with FRAM 30 glue at various temperatures [14].

Temperatures of tests in °C	$\bar{\tau}_{s}$ in kgf/cm²	$\bar{\sigma}_{om}$ in kgf/cm²	S_{om} in kgf/cm²
20	250	470	60
80	200	160	29
100	90	95	23
150	19	—	—

A check on the possibility of using FRAM 30 glue for production of glue-welded, glue-riveted and glue-threaded joints did not give positive results in connection with its reduced fluidity and poor ability in filling clearances, and also in connection with necessity of creating high specific pressures (8-20 kgf/cm²) on the glue layer in process of hardening the glue.

The basis of epoxy glues are epoxy resins consisting of linear polymers. These resins are usually obtained by condensation of diatomic phenols (more frequently diphenylpropane) with epichlorohydrin or dichlorohydrin. During interaction with different catalysts

(solidifiers), linear polymers are turned into polymers of three-dimensional structure with high adhesional properties. This permitted the successful use of epoxy resins as various glues. The majority of industrial resins for manufacture of glues are obtained from epichlorohydrin and diphenylpropane (dihydroxy diphenyldimethylmethane).

Epoxy glues possess good physical and mechanical and dielectric properties, good adhesion to almost all materials – metals, plastics, ceramics, poreclain, testiles, and so forth. As compared to other glues they are less sensitive to deviations in composition formulas, thickness of glue layer in glued and glued composite joints, exposed holding, and conditions of pressing. These glues harden with a small degree of shrinkage both at ordinary and also at raised temperatures, possess good fluidity at the time of pressing, and ability to fill clearances, and behave satisfactorily during aging. They are also corrosionally inactive in relation to almost all glued materials, and are resistant to the action of water, fuel media, and oils.

The nature of the hardener has a great effect on properties of glue compositions (temperature and rate of hardening, viability, mechanical strength, heat resistance, gluing property, and others). Thus, in the case of using a hardener of basic character (amine hardeners), epoxy glues can harden at room temperature, in the case of acid hardeners – during heating.

The process of gluing self-setting epoxy glues and producing glued composite joints can be noticeably accelerated by using preheating to temperatures on the order of 100-120°C. This also permits somewhat increasing the strength of the joints. Thermosetting glues are more heat resistant than the self-setting glues.

Glue compositions prepared from pure epoxy resins possess increased viscosity, which leads to an increase in specific expenditure of glue and accordingly to a greater expenditure of scarce resin. Furthermore, glued and glued composite joints carried out on these glues, frequently have lowered elasticity and resistivity to accelerated aging. For removal of this deficiency there are

introduced plasticizers (for example, polyesters) or what is more effective, the epoxy resins are inoculated with other resins – polyesters, phenols, melamines, polysulfides (thiokols), and others.

Considerable successes have been attained in this direction by domestic scientific research organizations – NIIPM [The Scientific Research Institute of Plastics], TsNIISK [The Central Scientific Research Institute of Structural Parts], VIAM [The All-Union Scientific Research Institute of Aviation Materials], and others, creating a whole series of modified epoxy glues possessing a complex of rational physico-technological characteristics and which are comparatively cheap.

Glue VK 32-EM consists of pure epoxy resin ED 6 (100 parts by weight), a hardener – maleic anhydride (30 parts by weight), and a filler – Portland cement 400 (50-100 parts by weight) [13]. Before use, the glue is prepared from two components: cement mixed with resin, and maleic anhydride which is toxic. The glue is intended for gluing of metals (steel, Duralumin) to each other and with heat-resistant foamed plastics, and is also recommended for production of glue-welded joints [11, 13]. Gluing is produced at 150-160°C during 3 h under a pressure of 0.5-1.0 kgf/cm^2. Viability of the glue amounts to 6-10 days. In the case of welding by glue, its viability is 24-28 h.

With hardening of the glue layer there is observed insignificant shrinkage of it. The glue with minimum content of filler possesses moderate viscosity and ability to fill clearances. Increasing the content of filler in the composition of the glue decreases its shrinkage during polymerization and the coefficient of thermal expansion, and increases the density and plasticity of the glue layer, but leads to growth of viscosity and reduction of water-resistance and chemical resistance of the glue. In the case of carrying out heat treatment of joints made with VK 32-EM glue at temperatures on the order of 100-120°C, the glue obtains increased fluidity and therefore can flow out from under the overlap.

Glued joints possess high strength during shift and uniform breakaway (Tables 11 and 12), and also satisfactory stress rupture strength and endurance. However, they have lower tensile strength during nonuniform breakaway (at 20°C, 15-20 kgf/cm) which is caused by insufficient elasticity of the glue layer. At temperatures over 60°C, strength of joints, decreases sharply (Table 11). Absence of external pressure during polymerization of the glue has little effect on the strength of the glue and glue-welded joints.

Table 11. Shear strength τ_B in kgf/cm^3 of glued joints [14].

Glue	Material	Temperature of test in °C				
		−60	20	60	100	150
VK 32-EM	Duralumin D16AT, anodized	120	170	160	50	—
	Steel 30KhGSA, sand blasted	247	270	275	60	—
FL 4S*	Duralumin D16T, cleaned with emery paper	128	116	51	7	—
L 4	Duralumin D16 plated	50	60	8	—	—
	Steel EI654, sand blasted	15	60	10	—	—
Epoxy P and epoxy Pr	Duralumin D16AT, anodized	95	120	130	135	—
	Duralumin D16AT, cleaned with paper	160	210	240	240	10
	Steel 30KhGSA, sand blasted	310	340	350	310	25
K 153	Duralumin D16AT, (anodized) + + glass laminate EF 32-301	76	180	75	—	—

* Data produced by the authors

Table 12. Uniform breaking strength σ_{om} in kgf/cm^2 of glued joints of Duralumin D16, cleaned with emery paper [14].

Glue	Temperature of test in °C			
	−60	20	60	100
VK 32-EM	—	450	—	—
L 4	300	130	125	—
Epoxy P	500	445	440	440
(Epoxy Pr)				
K 153*	108	135	125	—
FL 4S**	—	124	14	—

*Glued alloy D16T plated.
**Data produced by the authors.

A more detailed study conducted on the process of manufacture of glue-welded joints with application of VK 32-EM glue showed that it possesses a whole series of technological and other deficiencies. Thus, the process of welding by a layer of this glue, although it proceeds satisfactorily, however the presence of a nonmetallic filler (cement) in the composition of the glue inevitably leads to formation of slag inclusions and other defects in nucleus of the point. This is caused by the fact that this glue, even under increased forces of preliminary pressing, is pressed from the contact site and particles of the remaining glue, with switching on of the welding current, burn, passing into slag. Selection of optimum conditions of welding by a layer of VK 32-EM glue having a decreased quantity of cement (50 parts by weight), practically cannot be managed. Furthermore, at the time of applying the glue on the surfaces being joined and in the process of welding by glue there is observed an intense release of toxic gases, caused by the presence in it of highly volatile maleic anhydride. This requires special precaution in the work, and also special locations for the manufacture of glue-welded articles.

The possibility of producing glue-welded joints according to the method of capillary introduction of VK 32-EM glue into the overlap cavity is practically excluded in view of its poor penetrating ability.

Glue VK 32-EM ensures airtightness of glue-welded joints but has low water-resistance and low resistance in electrolytes of sulfuric acid anodizing and in electrolytes of chrome and chemical oxidizing. According to available source material, the prolonged effect of water and humid atmospheric conditions is to lower, for example, the strength of glued joints by 40% and more. As a check showed, under ordinary atmospheric conditions glue-welded joints made with this glue are subject to strong aging. Thus, raised toxicity, bad manufacturability, and other important deficiencies do not permit recommending VK 32-EM glue for production of glued composite connections.

Glue FL 4S consists of an alcohol-acetone solution of combined furyl-phenol-polyvinylacetyl resin, inoculated with epoxy resin ED 5, and plasticized by dioctyl sebacate. As a hardener there is used hexamethylenediamine or distillation residues obtained during its production (10% by weight of the glue composition), as filler – aluminum powder. The solvent is a mixture of alcohol and acetone in a 1:1 ratio.

This glue is prepared from two components: FL 4S resin, 100 parts by weight, and hexamethylenediamine, 3 parts by weight. The latter is added for hardening the glue directly before its use. Viability of the glue is not less than 8 h, therefore it is prepared with the calculation of using it during this time.

The FL 4S glue is obtained[2] as a result of modernization of the composition of FL 4 glue and possesses more rational physical and mechanical and technological properties than FL 4 glue. Into the composition of FL 4S glue there are introduced epoxy resin ED 5 (25 parts by weight) and a filler, promoting an increase in the density of the glue layer, changing the initial hardener and plasticizer. The process of production of the basis of the glue – furylphenolic resin – permitted increasing the dry resin residue from 25 to 45%. In combination with the introduction of epoxy resin it was possible to increase the total dry residue of the glue to 65-70% and thereby to sharply reduce the quantity of solvent in the glue and, consequently, to almost eliminate bubbling and shrinkage porosity in the glue layer during its hardening.

Introduction of dioctyl sebacate into the composition of FL 4S glue as plasticizer increased the elasticity of the glue layer. The plasticizer introduced earlier into the FL 4 glue – dibutyl phthalate belongs to the so-called migrating substances, i.e., has tendency to gradually shift to the surface of the hardened glue layer and evaporate from solid phase. This phenomenon leads to embrittlement of the glue with the passage of time. Dioctyl sebacate does not possess migrating properties, is nontoxic, is corrosionally inactive and is not scarce.

The FL 4S glue possesses high protective properties. It is stable in acid, alkali, and fuel media even in very thin layers; it is stable in the electrolytes used in anode oxidizing; it does not dissolve in polymerized state in acetone. It has good fluidity and therefore ensures reliable filling of all leaks in the internal cavity of the joints. The glue hardens in thick layer evenly without forming swellings.

Thanks to its good protective and technological properties, FL 4S glue is intended mainly for production of glue-welded joints. However, it can also be used for gluing of metals (alloys of aluminum, steel, and others), nonmetallic materials, and for production of glue-threaded joints.

In the normal gluing of metals, hardening of the glue is produced at a temperature of 155-160°C in 2 h.

Strength characteristics of joints made on FL 4S glue are given in Tables 11 and 12. From these data it is evident that glued joints are resistant to the influence of variations in temperatures in a range of ±60°C. The joints are insufficiently elastic, as witnessed by their very low efficiency during nonuniform breaking (at 20°C S_{om} = 9 kgf/cm).

Glue L 4 consists of pure uninoculated epoxy resin E 40 (100 parts by weight) a plasticizer – dibutyl phthalate (15 parts by weight) and a hardener – polyethylene polyamine (8 parts by weight) [13]. The glue hardens at ordinary temperature, therefore has short viability (40-60 min). However, it permits hot hardening (preheating at 120°C for 4 h under a pressure of 0.3-3 kgf/cm^2) which permits increasing strength and heat resistance of the joint more than 3 times. During hardening seam shrinkage is not observed. The heat resistance of the glue does not exceed 60°C. The glue seam is stable against the action of diluted acids, alkalis, gasoline, and oil.

Joints made with L 4 glue possess low strength and low heat resistance (Tables 11 and 12), therefore it is used basically for gluing of metals and nonmetallic materials in nonpower constructions. The glue possesses good hermetic sealing properties and therefore can be successfully used in the production of airtight constructions, working under small excess pressures, and also for hermetic sealing of clearances in articles during anode oxidizing of them. Gluing can be produced with very small specific pressures. The glue can be used in glue-threaded joints, especially for locking bolts and screws directly onto articles in the process of servicing and repair. Investigations showed, for example [10], that forces of unscrewing nuts and screws stopped by glue L 4 was not changed after operation of the articles in atmospheric conditions after 19 months and after additional tests for vibration in a frequency range of 20-180 Hz.

Glues epoxy P and epoxy Pr – hard, consisting of single-component systems and on the basis of hard epoxy resin E 41. Their properties are practically identical: they are nontoxic, are water-resistant, fill clearances well, are applied ready for use; viability is not less than 6 months. The glues are intended for gluing of metals and nonmetallic materials of the fiberglass laminate type. Glue epoxy P is prepared in the form of a powder, and epoxy Pr – in the form of rods. These glues can be applied only to a preliminarily heated surface. On surfaces heated to 80-120°C, subject to gluing, these glues are melted and then harden at 180°C in 2 h (or at 150°C in 5 h) under pressure of 0.5-3 kgf/cm^2. The glue layer can be applied also as a hot spray by means of special devices.

From Tables 11 and 12 it is clear that joints carried out on these glues possess high static strength especially during uniform breakaway in a rather wide range of temperatures (from -60 to +100°C). Furthermore, they also possess satisfactory stress rupture strength and endurance.

The specific character of technology of applying these glues on surfaces to be joined creates great practical inconveniences in the production of glue-welded joints. Thus, the use of powdery glue P

for production of glue-welded joints turned out to be in general, impossible, and epoxy Pr in the form of rods requires for qualitative application preheating the whole article evenly to 120-130°C, which is difficult to do in practice, and causes excessive spreading of glue over the surface being welded and flowing out of it from the joint zone.

An attempt at preheating the spout feeding the glue rods for the purpose of obtaining liquid glue did not lead to positive results, since the hot glue, or getting onto the cold surface rapidly congealed and penetrated poorly into the overlap clearance, had insufficient adhesion to the metal, and also form an uneven high glue ridge along the edge of the joint. In connection with unsatisfactory technological properties, epoxy P and Pr glues cannot be used for production of glue-welded joints. However epoxy P glue can be used in a number of cases for production of glue-threaded joints.

Glue K 153 is a composition consisting of epoxy resin ED 5, plasticized by polysulfide, the cubic remainder of hexamethylenediamine (or hexamethylenediamine) and a filler – Portland cement 400 (see Table 20). The glue seam hardens at room temperature in 18 h under pressure of 1.5-2 kgf/cm^2. The process of hardening can be accelerated by application of preheating: to 80°C, 6 h or to 100°C, 4 h. Viability of this glue is 1-1.5 h, therefore it should be prepared at the place of application with the calculation of possibility of using it during the time indicated. It possesses good fluidity and ability to fill the clearances. The presence in the composition of the glue of liquid thiokol (Table 20) promotes an increase in elasticity and airtightness of the glue seams. In gluing, the average expenditure of glue K 153 amounts to 300-350 g/m^2.

Glue K 153 is intended basically for joining of fiberglass laminate with metals, but can also be used for gluing alloys of aluminum, magnesium, steels, and brasses. However this glue may also be successfully used for obtaining glue-welded, glue-riveted and glue-threaded joints of the alloys mentioned, working in a range of

temperatures ∓60°C and without experiencing tearing forces in operation in the constructions, since the glue layer in hardened state is insufficiently plastic (see Chap. III, V and VI).

Glue K 153 possesses the highest dielectric properties as compared to all the other known glues. Thus, its specific surface electrical resistance amounts to $3.0 \cdot 10^{14}$ Ω, specific volumetric electrical resistance $3.6 \cdot 10^{13}$ Ω·cm, breakdown voltage (normal) 24.9 kV/mm [11, 14].

As can be seen from Tables 11 and 12, the strength characteristics of joints made on glue K 153 are comparatively low. Elasticity of joints made with this glue is noticeably increased in the case of application during gluing of an underlayer of more elastic glue, for example VK 3. The joints are resistant to the effects of fuel media, mineral oils, acetone and atmospheric air.

Glue KLN 1 [1] consists of a bi-component composition, consisting of a base and a hardener. The base consists of epoxy resin of grade ED 5 (100 parts by weight), active diluent – product DEG 1 (20 parts by weight), and a plasticizer – polysulfide of grade P (30 parts by weight). As a solidifier polyethylanepolyamine is used (10% of weight of the base).

Viability of KLN 1 glue after mixing the basis and the solidifier at a temperature of the air at the location not higher than 25°C and applying with a brush, amounts to 1.5-2 h. This glue hardens at room temperature. It is possible also to use warm hardening (heating to 26-80°C); in so doing, strength characteristics of the glued joint are increased considerably.

Glue KLN 1 is intended basically for production of glue-welded joints of aluminum alloys. However it can be successfully used for gluing of different ferrous and nonferrous metals, and also nonmetallic materials. It possesses good fluidity and ability to fill clearances. During gluing, the average expenditure of glue is 150-200 g/m^2.

Gluing of parts [1] should be carried out under a pressure of 0.5-2 kgf/cm^2 at a temperature at the location not lower than 18°C, since with a decrease in temperature, the process of polymerization of the glue is retarded. Increasing the temperature accelerates the process of hardening it. Exposed holding is 15-30 minutes. Duration of holding the joint under pressure during gluing depends on the temperature and configuration of the article. At 18-25°C holding should compose not less than 25 h, at 26-80°C – not less than 18 h, at 100°C – 4 h. A rise in temperature to 100°C is recommended to be conducted for 2-2.5 h. It is necessary to cool the glued parts under pressure to a temperature of 40-50°C (to avoid formation of sharp concentrations of internal stresses in the glue seam).

Joints made with glue KLN 1 possess considerable efficiency during static shear and very high stress rupture strength (Tables 13 and 14). They resist loads well during uniform and nonuniform breaking, which testifies to the high plasticity of the glue layer (Table 15).

Table 13. Shear strength $\tau_{в}$ in kgf/cm^2 of joints made with glue KLN 1 (stripped with emery paper).

Material	Temperature of test in °C			
	−60	20	60	80
Duralumin D16	146 / 132–187	150 / 146–193	45 / 35–52	27 / 22–39
Steel 30KhGSA	—	244 / 202–300	42 / 33–48	24 / 11–62

Table 14. Stress rupture strength during shear τ_B in kgf/cm^2 of joints of Duralumin D16 made with glue KLN 1 (stripped with emery paper).

Temperature of tests in °C	Control samples	Heating during		
		100 h	500 h	1000 h
20	149 / 120—160	185 / 170—210	209 / 193—225	209 / 185—240
80	28 / 15—30	142 / 118—171	172 / 142—192	166 / 138—194

Table 15. Tensile strength of Duralumin D16.

Strength	Temperature in °C		
	—60	20	60
σ_{om} in kgf/cm^2	485 / 320—450	205 / 191—146	67 / 53—76
S_{om} in kgf/cm	17 / 11—25	22 / 18—28	3 / 2—6

However, joints made with KLN 1 glue have limited heat resistance: they are able to work during heating only to 60-80°C (Table 13 and 16).

The high thermostability of the glue layer in joints shows that the glue ages very slowly during heating. The increase in the strength of joints with an increase in the duration of heating (Table 17) testifies to the ability of the glue layer to be strengthened during prolonged heating and thereby to ensure reliable working of the joint under conditions of precipitation hardening. Destruction of glued samples during testing under conditions of room temperature had a cohesive character, but at 80°C — adhesional.

Table 16. Shear strength τ_B in kgf/cm^2 of joints made with KLN 1 glue with different treatment of the surface (according to Ye. L. Apartseva).

Material	Surface state	Temperature of tests in °C: 20	80
Duralumin D16AT	Anodized with filling in dichromate	155 / 133—167	40 / 28—52
	Anodized with filling in water	200 / 200—200	60 / 48—65
	Plating, stripping with emery paper	124 / 113—140	60 / 40—70
Steel 30KhGSA	Cadmium-plated	177 / 163—200	70 / 65—80
	Galvanized	105 / 96—120	37 / 30—47
	Sand-blasted	156 / 133—180	40 / 35—46

Table 17. Shear strength τ_B in kgf/cm^2 of joints of Duralumin D16 made with glue KLN 1.

Temperature of tests in °C	Control samples	Action of water during days: 5 days	15 days	30 days
20	148 / 117—180	132 / 123—160	102 / 93—143	95 / 73—127
80	27 / 25—28	35 / 23—53	33 / 30—38	11 / 10—17

The strength of joints made with KLN 1 glue essentially depends on the state of the surfaces being glued. The highest strength of glue joints takes place in the case of anodizing or cadmium-plating of the surfaces, and the least – in the case of stripping with abrasive paper and zinc-coating (Table 16). This caused by the character of the microgeometry of surfaces being glued, essentially affecting the adhesional ability of many gluing substances. Thus, anodizing of aluminum alloys will form on the surface a layer with

uniform fine-pore structure, which for the majority of glues promotes an increase of adhesion and, consequently, strength of the gluing. Cleaning with emery paper or steel brush ensures a well-developed surface with nonuniform scratches and holes, which can give micro-unglued spots, decreasing the strength of the glue connection.

Fluid glues, filling clearances well and not requiring great molding forces for hardening (VK 1, VK 1MS, and others), are low in sensitivity to the character of preparation of the surface. In this case, strength indices of glue connections during different methods of preparation, as a rule, are within limits of natural scattering of test results.

The KLN 1 glue under conditions of ensuring protection of facets of the joint by varnish and paint coatings possesses satisfactory water-resistance (Table 17). Resistance of the glue to the action of solvents, fuel media, and oils is fully sufficient (Table 18). The certain increase in strength of connections thus appearing in comparison as compared to the strength of control samples can be explained by the fact that in accordance with method of tests, control samples were tested for 5 days from the moment of gluing, and joints made with KLN 1 glue increase the strength in 10 days after the beginning of hardening.

Table 18. Shear strength τ_B kgf/cm^2 of joints of Duralumin D16 made with glue KLN 1 after the action of different media for 5 days.

Medium	Temperature of tests in °C		Medium	Temperature of tests in °C	
	20	80		20	80
Control samples...	151 / 127—178	23 / 17—30	Alcohol-rectifier.....	150 / 130—158	26 / 20—35
Kerosene..........	168 / 147—193	47 / 43—52	Transformer oil.......	152 / 133—200	68 / 53—80
Gasoline B-70.....	166 / 143—187	47 / 37—60	Oil B-3V.............	182 / 180—203	75 / 73—7[illegible]

The resistance to change of KLN 1 glue is also satisfactory (Table 19) and is on a level of stability with other domestic and foreign epoxy glues.

Table 19. Shear strength τ_B in kgf/cm^2 of joints of Duralumin D16T made with KLN 1 glue after tests in a tropic chamber.

Temperature of test in °C	Control samples	Duration of effect		
		10 days	20 days	30 days
20	161 / 150—184	128 / 118—147	78 / 90—133	74 / 46—90
80	28 / 24—29	38 / 34—42	17 / 11—29	30 / 20—39

Glues EPTs and EORTs consist of a self (warm) setting composition, consisting of epoxy resin ED 5, ED 6 (or EDF 3), inoculating additives - polyether acrylates MGF 9, TGM 3, a solidifier in the form of cubic residue hexamethylene diamide (GMDA), polyethylene polyamines and a filler of Portland cement 400, and others (Table 20) [17, 18]. The glues are prepared from separate components or from compounds consisting of a mixture of resin with inoculating additives.

Table 20. Composition of epoxy-cement glues in parts by weight.

Components	EPTs 1	EPTs 2	EORTs	EOSTs 2	K 153
Epoxy resin:					
ED 5	100	100	—	100	100
ED 6	—	—	100	—	—
Polyester:					
MGF 9	20—30	—	—	10	10
TGM 3	—	20—30	—	—	—
Hydroxyterpene solvent	—	—	40	—	—
Hydroxyterpene resin	—	—	—	40	—
Thiokol of grade NV	—	—	—	—	20
Cubic residues	25	25	30	30	23
PEPA (polyethylene polyamine)	(10)	(10)	(15)	(15)	(15)
Portland cement, grade 400	100—400	100—400	100—400	100—400	100—400

These glues were developed by TsNIISK and are intended basically for gluing of aluminum, asbestos cement, rigid-foam plastics and foam plastics and other materials used in structural constructions and contain less than 20% epoxy resins. However, the glues mentioned, after certain modernization of their composition can be successfully used for production of glue-welded, glue-riveted and glue-threaded joints.

Introduction of inoculants - polyethers - into epoxy resins permits sharply lowering their viscosity and thereby increasing the ability of the glue to fill the clearances, frost-resistance of the glue and glued-composite joints. Severe lowering of the viscosity of the glue, attained by modification of the resins, made it possible to introduce in it a large quantity of filler (cement) (Table 20), which permitted noticeably reducing the specific expenditure of scarce epoxy resins and, consequently, to considerably lower the cost of these glues. When gluing aluminum 100-250 parts by weight of cement is necessary, and when gluing asbestos cement - its maximum quantity - 200-400 parts by weight, where this quantity depends on the method of application and the grade of the epoxy resin.

Still greater lowering of viscosity, which is very important for mechanization of application of glue in the production of glue-composite constructions, occurs during introduction into its composition, instead of polyether acrylates, hydroxyterpene solvent - a cheap and nonscarce product of the oxidation of turpentine. In this way there is obtained the high-technologic glue EORTs (Table 20).

If, as modifying additions, simultaneously hydroxyterpene resin and polyester MGF 9 are used, then there can be obtained the composition EOSTs (Table 20), differing in increased impact strength. For production of glue-welded joints, the most promising are the EPTs glues.

Viability of EPTs glues at a temperature of air at the location of 18-20°C, and application by brush or spatula under conditions open holding amounts to 1.5 h. To glue aluminum parts it is necessary

to have a pressure of 0.2-0.6 kgf/cm^2 at a temperature at the location of 18-20°C. Optimum holding during cold method gluing is under pressure for twenty-four hours. However, the glued joint reaches sufficiently high strength even after the expiration of 12 h from the moment of its manufacture.

In the manufacture of glued and glued-composite constructions open and covered holdings of glue are unavoidable. The recommended duration of holding for freshly prepared EPTs glues [17]: glues on ED 5 resin, open — 30 min, covered — 90 min; glues on EDF 3 resin, open — 30 min, closed — 60 min. The EPTs glues are capable also of hardening during heating to 60-80°C (warm method); in so doing strength characteristics of the glued joint are considerably increased, and also the hardening process is considerably accelerated. Thus, when heating to 80°C, holding of a glued aluminum joint under pressure of 0.2-0.6 kgf/cm^2 takes only 15-20 min, and at 60°C and the same pressure — 25-30 min.

Joints carried out on EPTs glues, at room temperature possess high strength during shift and uniform breakaway, resilience and stress rupture strength. However, these joints are poorly heat-resistant: are capable of prolonged work with heating only to 60-80°C, and short-term to 120°C. Tensile strength of joints of Duralumin made with EPTs glues during static shear is equal to 80-150 kgf/cm^2 at room temperature [14, 17]. Strength of joints on EPTs 2, EORTs, and EOSTs glues is somewhat lower (50-80 kgf/cm^2) than on EPTs 1 glue. At the same time, EPTs 1 glue works worse during nonuniform breaking, which is explained by its lower elasticity. Tensile strength of joints made with EPTs 1 glue during uniform breaking, obtained during testing of round cylindrical samples, composes $\frac{160}{140-186}$ kgf/cm^2, and cruciform samples $\frac{132}{123-134}$ kgf/cm^2. The difference can be explained by the different character of loading of the samples [10].

Joints carried out on EPTs glues possess considerably greater efficiency under impact loads than many other epoxy glues. Thus, for example, the resilience of joints made with EPTs 1 glue, hardened for 3 days at room temperature, equals $\frac{7{,}81}{13{,}2-2{,}85}$ kgf/cm^2.

When gluing aluminum alloys with EPTs glues, the character of preparation of surface more strongly affects the strength of the joints than when gluing with other epoxy glues. For comparison, samples were glued of alloy AM 6 treated preliminarily with emery paper, chemical etching in a solution of orthophosphoric acid, and by means of electrochemical oxidizing. Strength of gluing turned out to be the highest after oxidizing and the least after mechanical stripping. Application, in this case, of electrochemical or chemical oxidizing gives practically identical effects [17].

It is customary to assume that the aluminum surface film forming as a result of oxidizing, thanks to its porosity sharply increases the surface of the material, which is one of the causes of increase in strength of the gluing. When gluing aluminum with rubber glues, oxidizing provides no gain in strength regardless of what alloy was glued. And, in the case of gluing with KS 609 glue, anode oxidizing leads even to considerable lowering of the shear strength of joints (see Table 4).

With any method of preparation of metal for gluing, degreasing is obligatory. Degreasing of aluminum alloys can be carried out in alkali baths and thorough washing with acetone. There is shown below the effect of the degreasing method on the shear strength in kgf/cm^2 of joints of alloy AMg 6M with a thickness of 2 mm with 15 mm overlap made with EPTs 1 glue.

In comparing the given data there is seen a considerable difference in the strength indices of glued joints carried out with the use of degreasing and without it.

Joints made with EPTs glues possess good water-resistance. For example, shear strength of aluminum joints made with EPTs 1 glue after 30 days stay in water is changed only 10-15%; here the maximum water absorption does not exceed 0.15%.

Acetone.................................... $\frac{118}{96-140}$

Alkaline solution (solution hydroxide NaOH 10 g/l; trisodiumphosphate 50 g/l; water glass 30 g/l)..... $\frac{126}{102-150}$

Solution OP-10 (0.2%)......................... $\frac{116}{97-139}$

Without degreasing............................ $\frac{84}{63-129}$

The EPTs glues are also sufficiently resistant to the action of solvents (especially acetone), fuel media, and oils. Their stability to change is fully satisfactory.

Heat-Resistant Glues

Production of modern machines, instruments, and mechanisms presents new, ever more stringent requirements for heat resistance both for materials themselves, intended for manufacture of given articles, and also for elements of joints. In connection with this, there appeared the necessity for development and application for manufacture of glued and glued-composite joints of heat-resistant, and in a number of cases, of high heat-resistant glue compositions possessing high physical and mechanical and technological properties.

Glues VK 1, VK 1M, VK 1MS, VK 7 are heat-resistant compositions consisting of a modified epoxy resin, a hardener, and a filler. They harden only with heating, are sufficiently technologic, possess good resistivity to thermal aging, ensure production of sufficiently dense and monolithic glue seams, and are nontoxic.

The glues are very resistant to the action of water, oil, gasoline, and also solvents and electrolytes used in process of anodizing.

The noted positive properties of these glues open wide possibilities for use of them, mainly in production of glue-welded, glue-riveted and glue-threaded joints. Simultaneously with this, possessing good adhesion to metals, they can be successfully used also for gluing of alloys of aluminum and steels.

Glue VK 1 consists of a composition on the basis of epoxy resin, modified by elementorganic compound (being simultaneously a hardener) and a filler (zinc powder). Viability of it is 72 hours. Specific gravity of glue before and after polymerization equals 1.29 g/cm^3. It is recommended [14] that gluing be performed under a pressure of 0.5-1 kgf/cm^2 at a temperature of 150°C and holding for 1 h, or at 120°C and holding for 3 h, or at 100°C and holding for 5 h. Absence of molding during polymerization of glue has little effect on strength characteristics of glued and glued-composite joints.

The VK 1 glue possesses moderate viscosity at the time of gluing and fills clearances well. However, in the process of hardening at a temperature of 100-110°C, it acquires sharply increased fluidity, which leads to flowing out of the glue from the clearances of the joint in the case of a slope of plane of the combinable parts to the horizon of more than 10-15°. This property of the glue essentially limits its region of application, especially in constructions having considerable curvature. Preliminary open holding of the surface of the part with the layer of glue applied at 80°C for 1-1.5 h improves the heat resistance of the joint and decreases the spreading ability of the glue layer.

Joints made with VK 1 glue, possessing considerable strength at ordinary temperature, maintain sufficient efficiency up to 150°C (Table 21). In strength on uniform breakaway at a temperature of 20°C, joints made with VK 1 glue exceed all other known glued joints (Table 22), and simultaneously possess considerable strength during nonuniform breakaway in a temperature range of 20-150°C (Table 23). This testifies to the high elasticity of the VK 1 glue layer both at ordinary and also at raised temperatures.

Table 21. Shear strength τ_n in kgf/cm^2 of glued joints under conditions of different temperatures.

Glue	Material	Temperature of tests in °C								
		−60	20	40	60	100	150	200	230	250
VK 1	Duralumin D16T, cleaned with emery paper	164 / 144—181	145 / 117—178	—	—	154	87	—	—	12 / 10—15
VK 1	Steel 30KhGSA, cleaned with emery paper	—	206	208	—	226	79	—	—	—
VK 3M	Duralumin D16T, cleaned with emery paper	—	171 / 160—183	187 / 164—217	193 / 176—217	178 / 169—189	88 / 86—101	—	—	—
VK 3MS	Duralumin D16T, cleaned with a steel brush	—	180 / 176—191	198 / 182—200	176 / 167—183	131 / 117—155	41 / 37—49	—	—	—
VK 7	Duralumin D16T, plated, cleaned with a steel brush	89 / 77—118	87 / 76—109	—	—	—	—	96 / 88—110	83 / 57—113	26 / 16—36
VK 7	Duralumin D16, plated, anodized	—	32 / 22—45	—	—	—	—	43 / 33—85	33 / 22—91	—
VK 7	Steel 30KhGSA, sand blasted	—	128 / 105—146	—	—	—	—	196 / 187—206	166 / 156—180	23 / 16—33
VK 7	Titanium alloy OT 4	—	107 / 88—118	—	—	—	—	—	100 / 88—111	20 / 19—23

Table 22. Uniform breaking strength σ_{om} in kgf/cm^2 of glued connections at different temperatures (liquid glues were used).

Glue	Material	Temperature of tests in °C								
		−60	20	60	80	100	150	200	250	300
VK 1	Duralumin D16, cleaned with emery paper	789	743	450	441	—	207	—	—	—
VK 1M		—	296	155	77	38	—	—	—	—
VK 7		—	617	576	—	—	69	48	27	—
VK 3	Duralumin D16AT, anodized	500	200	160	120	80	—	—	—	—
	Steel 30KhGSA, sand blasted	500	200	—	130	110	—	—	—	—
VK 32-200	Duralumin D16AT, anodized	253	206	—	—	96	—	70	42	—
VK 32-250		400	183	—	—	117	—	76	59	28
VK 4	Steel 30KhGSA, sand blasted	400	180	—	—	—	—	—	70*	35
VS 10T		—	585	—	400	—	270	190	—	150
VS 350**		—	360	—	—	—	—	150	—	100

* Testing at 275°C.

** At 350°C σ_{om} = 76 kgf/cm^2.

Table 23. Nonuniform breaking strength S_{om} in kgf/cm of glued joints at different temperatures.

Glue	Material	Temperature of tests in °C					
		20	80	100	150	275	300
VK 1	Duralumin D16, cleaned with emery paper	22	—	19	18	—	—
VK 7		12	—	11	9	6*	—
VK 3	Duralumin D16AT, anodized**	50	25	15	—	—	—
	Steel 30KhGSA, sand blasted**	65	50	40	—	—	—
VK 32-200	Duralumin, anodized**	25 30	—	—	13–14	—	—
	Steel 30KhGSA, sand blasted**	60	—	—	—	—	—
VK 32-250	Duralumin, anodized	25–30	—	—	13–14	—	—
VK 4	Steel 30KhGSA, sand blasted	32	—	—	—	9	6
	SAP**	28	—	—	—	7	4
VS 10T	Steel 30KhGSA, sand blasted	12	—	27	16	—	7

* Testing at 250°C.

** Literary source [14].

Designation: SAP = Sintered aluminum powder.

Joints made with VK 1 glue also possess high stress rupture and thermostability, which testifies to their slight tendency to thermal aging. For example, shear strength of joints of plated Duralumin D16AT cleaned with emery paper composes at 20°C, 110 kgf/cm^2 (base 434 h); and at 150°C, 23 kgf/cm^2 (base 100 h).

Further improvement in the composition of VK 1 glue led to the creation of new, more technological glues, VK 1M and VK 1MS. Into the composition of VK 1M glue there is introduced a second hardening catalyst – polyethylene polyamine (5 parts by weight) and 8-10% solvent (dimethylketone). In connection with this, the viability of VK 1M glue is sharply reduced as compared to the viability of VK 1 (to 8-10 h). Viscosity of this glue grows rapidly, and after 30-36 h it is turned into a solid gel. The glue must be prepared not earlier than 1 h prior to application. In so doing, it is necessary to carefully watch the content of solvent in it, since with an increase of content of only 5%, porosity appears in the hardened glue layer and, consequently, its airtightness is disturbed. The prepared glue scarcely changes its initial viscosity in 6-8 h.

The glue is intended for gluing of metals. Besides this, it finds application in glue-threaded connections both as a hermetically sealing component and for locking of bolts and screws.

As can be seen from Table 21, joints made with VK 1M glue possess somewhat higher shear strength than joints made with VK 1 glue. However their strength during uniform and especially during nonuniform breaking is considerably lower, which is testified to by the reduced elasticity of the glue layer. Thus, the nonuniform breaking strength of connections of Duralumin D16 made with VK 1M glue equals only 15 kgf/cm at 20°C, and 13 kgf/cm at 100°C.

Joints made with VK 1M glue possess especially high thermostability and good water-resistance and tropic stability (Tables 24-26). The VK 1M glue can be used in a number of cases in the production of glue-welded constructions of different purpose.

Table 24. Characteristics of thermostability (τ_B in kgf/cm^2) of joints of Duralumin D16, cleaned with emery paper, made with VK 1M glue.

Temperature of tests in °C	Control tests	Testing after aging 300 h	Temperature of tests in °C	Control tests	Testing after aging 300 h
20	$\frac{136}{107-141}$	$\frac{144}{131-183}$	80	$\frac{155}{144-172}$	$\frac{151}{139-170}$
60	$\frac{179}{161-193}$	$\frac{152}{143-171}$	100	$\frac{122}{113-139}$	$\frac{146}{132-165}$

Table 25. Characteristics of water-resistance (τ_B in kgf/cm^2) of joints of Duralumin D16 made with VK 1M glue.

Temperature of tests in °C	Control tests	Duration of water effect		
		5 days	10 days	20 days
20	$\frac{122}{111-154}$	$\frac{128}{119-134}$	$\frac{114}{103-124}$	$\frac{130}{121-149}$
80	$\frac{163}{114-196}$	$\frac{179}{173-191}$	$\frac{142}{128-158}$	$\frac{166}{160-179}$
100	$\frac{108}{90-116}$	$\frac{80}{67-90}$	$\frac{73}{60-87}$	$\frac{92}{89-104}$

Table 26. Characteristics of tropic resistance of joints of Duralumin made with VK 1M glue.

Temperature of tests in °C	Control tests	After tests in tropic chamber for 15 days	Temperature of tests in °C	Control tests	After tests in tropic chamber for 15 days
20	$\frac{171}{160-183}$	$\frac{132}{112-147}$	80	$\frac{193}{176-217}$	$\frac{161}{150-173}$
60	$\frac{187}{164-217}$	$\frac{146}{131-153}$	100	$\frac{178}{169-189}$	$\frac{126}{108-142}$

Glue VK 1MS consists of liquid epoxy resin, modified by elementorganic compound, and a filler. It does not contain solvent (dry residue 99.4%) and during hardening will form a monolithic airtight seam. Hardening of the glue composition occurs at 150°C in 1 h, at 120°C, 3 h, or at 100°C, 5 h.

Glue VK 1MS is specially developed for glue-welded joints, taking into account the requirements in the technology of their manufacture. It possesses equally good adhesion to alloys of aluminum and steels.

A distinctive feature of the glue composition VK 1MS is the presence in its composition as a diluent of high-volecular epoxidized alcohols, which, in contrast to solvent, do not evaporate during hardening of the glue, and chemically interacting with the base of the glue, enter into its composition. This ensured the possibility of creation of a glue with moderate viscosity, sufficient viability, and good technological properties without impairment of the basic positive qualities of an epoxy glue — absence of solvent and shrinkage during hardening. Initial moderate viscosity of the glue remains practically constant for 1.5-2 h.

As can be seen from Table 21, the strength of joints made with VK 1MS glue at ordinary temperature exceeds the strength of joints carried out on VK 1 and VK 1M glues, and at the same time these joints preserve considerable efficiency up to a temperature of 150°C. Glue VK 1MS is especially heat resistant (Table 27), exceeding in this respect VK 1 glue, which testifies to its high resistivity to thermal aging and ability, thanks to this, to work reliably during prolonged (up to 500 h) heating. Along with this, it possesses sufficiently high water-resistance and tropic stability (Tables 28 and 29). Therefore, in shielding the facets of the joint by a system of varnish and paint coatings it can be used successfully in articles intended for work under different climatic conditions.

Table 27. Characteristics of thermostability (τ_{B} in kgf/cm^2) of joints of Duralumin D16, cleaned with emery paper, made with VK 1MS glue.

State of samples during test	Temperature of tests in °C			
	20	60	80	100
Control samples..................	143 / 110—155	198 / 182—209	176 / 167—183	131 / 117—155
After holding for 300 h at the given temperature..............	152 / 145—197	167 / 158—181	176 / 167—183	178 / 171—185

Table 28. Shear strength τ_{B} in kgf/cm^2 of joints of Duralumin D16 made with VK 1MS glue after the effects of water and temperature.

Temperature of tests in °C	Control samples	Duration of effect of water		
		5 days	10 days	20 days
20	122 / 111—154	128 / 119—134	114 / 103—124	13[illegible] / 121—149
80	163 / 114—195	179 / 173—191	142 / 128—158	166 / 160—179
100	105 / 90—116	82 / 67—90	73 / 60—87	99 / 89—104

Table 29. Shear strength τ_{B} in kgf/cm^2 of joints of Duralumin D16 made with VK 1MS glue after testing in a tropic chamber.

State of samples	Temperature of tests in °C			
	20	60	80	100
Control samples....................	171 / 150—188	187 / 164—217	193 / 176—217	178 / 169—189
After holding for 15 days in tropic chamber....................	134 / 112—147	146 / 141—153	161 / 150—173	126 / 108—142

Glue VK 7 consists of a high heat-resistant composition containing modified epoxy resins, a hardener and a filler (titanium dioxide). The solvent for it is ethylcellosolve. Viability of the glue is especially high (with a hardener – up to 3 months). This glue can be used both for production of glue-welded and glue-riveted joints, and also for gluing of different metals working in constructions at temperatures from -60 to +250°C. It has especially high adhesion to steels and titanium alloys.

In Tables 21-23 strength characteristics are given for joints made with VK 7 glue. As can be seen from Table 23, shear strength of joints made with VK 7 glue at ordinary temperature is noticeably lower than the strength of joints made with VK 1, VK 1M and VK 1MS glues, but it remains practically constant up to a temperature of 230°C, whereas joints made with the glues mentioned are much weakened even at temperatures of 150°C. Joints made with VK 7 possess high strength on uniform breakaway at 20°C, yielding only to joints made with VK 1 glue. The nonuniform breaking strength of these joints is reduced.

Joints made with VK 7 glue possess sufficiently good thermostability, stress rupture strength, and also vibration- and water-resistance at normal and raised temperatures (Tables 30-32). This testifies to the high resistivity of the glue layer to precipitation hardening.

Table 30. Stress rupture strength (τ_B in kgf/cm²) of joints of Duralumin D16T made with VK 7 glue.

Temperature of tests in °C	τ_B	Time to destruction in h
20	50	160
130	35 16	62 96
250	35 16	36 39

Table 31. Fatigue shear strength $\tau_в$ in kgf/cm^2 of joints of Duralumin D16 made with VK 7 glue.

Temperature of tests in °C	τ_o	Number cycles prior to destruction	Note
20	70	1 000 000	Sample was destroyed
	50	10 000 000	Without destruction
230	50	1 582 000	Sample was destroyed
	40	3 635 000	The same
	35	10 000 000	Without destruction
250	30	10 000 000	The same
	35	10 000 000	" " "

Table 32. Shear strength $\tau_в$ in kgf/cm^2 of joints of Duralumin D16 made with VK 7 glue after the effect of temperature and water.

State of samples during testing	Temperature of tests in °C		
	20	230	250
Control samples (in initial state).....	$\frac{87}{79-93}$	$\frac{91}{57-105}$	$\frac{26}{17-35}$
After holding for 15 days at given temperature..........................	$\frac{64}{56-70}$	$\frac{63}{49-74}$	$\frac{26}{10-29}$
After influence of water for: 15 days..........................	$\frac{83}{79-87}$	$\frac{81}{74-91}$	$\frac{36}{33-36}$
30 days..........................	$\frac{87}{75-96}$	$\frac{64}{50-77}$	$\frac{19}{17-25}$

Glue VK 9 consists of a composition on the basis of modified epoxy resin with addition of a catalyst capable of hardening at room temperature. As filler for the glue aluminum powder is used. The glue is nontoxic and can be used for gluing metals, nonmetallic materials, and production of glue-welded joints. Its viability is 2 h 30 min at a temperature of 18-23°C. Average expenditure of glue during gluing is near 160-200 g/m^2. Contact of this glue, for example, with Duralumin D16 anodized or cleaned with emery paper (metallic brush), does not cause corrosion.

As can be seen from Table 33, joints made with VK 9 glue possess considerable strength at 20°C in combination with relatively high heat resistance, which testifies to the essential advantages of this glue as compared to all other known self-setting glues.

Table 33. Shear strength τ_{B} in kgf/cm^2 of joints of different metals made with VK 9 glue.

Material	Temperature of tests in °C					
	—60	20	125	150	200	250
Duralumin D16, cleaned with emery paper....	150	150	50	30	12	10
Duralumin D16 anodized....................	53	65	39	23	—	—
Titanium alloy OT 4 sand blasted..........	137	183	78	50	—	—
Steel 30KhGSA, sand blasted...............	206	229	49	32	—	—

The conducted investigations showed that joints carried out with VK 9 glue are resistant for 12 days against the effect of special fuel media, oil, and gasoline, and practically do not change their mechanical characteristics after a stay of 30 days in water and in an artificial tropical climate chamber and, consequently, can be used under any climatic conditions. They are also resistant to the action of electrolytes used during anode oxidizing.

Glues VK 3, VK 32-200, VK 32-50 and VK 4 are phenolrubbers; they successfully combine in themselves the positive qualities of phenolformaldehyde resins and rubbers: the high heat resistance of the former and the increased elasticity of the second. The glues represent reaction products of phenolformaldehyde resins (varnish IF for glue VK 32-200 and VK 3 and resin resol 300 for glue VK 32-250) with acrylonitrile rubber SKN-40 and its modification. It is considered that, as a result of reaction, there will be formed a block-copolymer of three-dimensional structure where, depending upon the ratio of components, strength characteristics and thermal stability of the glued joints are changed during shift.

These glues possess good adhesion to different metals, plastics and other nonporous nonmetallic materials. It is possible to use them in liquid form and in the form of films. Strength during shift of joints carried out on film glues is somewhat lower than the strength of similar connections carried out on liquid glues.

It is recommended in [14] that the following technology of gluing with liquid glues be used: apply VK 3 glue in two layers; after application of the first layer – open holding for 30 min at a temperature of 20°C; after the second layer – 30 min at 20°C and 90 min at 65°C, then polymerization of the glue at 165°C ± 5° for 1 h under a pressure of 5-10 kgf/cm^2.

Glue VK 32-200 is also applied in two layers; after application of the second layer it undergoes open holding for 20 min at 20°C and 30 min at 65°C, then the glue is at polymerized 180°C for 1-2 h under a pressure of 6-20 kgf/cm^2 (depending upon the quality of trimming of the glued surfaces). The technology of gluing with VK 32-250 glue is practically the same as for VK 32-200 glue, but it is hardened at 200°C. Hardening of VK 4 glue is produced at 200°C for 2 h under a pressure of 10-20 kgf/cm^2. Its viability is 24 h.

As can be seen from Tables 21-23 and 34, joints carried out on the glues enumerated possess sufficiently high strength indices under shear and breakaway in a wide range of temperatures (especially glues VK 32-200, VK 32-250, and VK 4). A characteristic feature of the glues examined is the fact that value of strength of glued joints of Duralumin and steel during shear and uniform breaking differ insignificantly one from another. In respect to strength on nonuniform breaking of joints made with these glues, they exceed joints made with other heat-resistant glues. This shows that the glues enumerated ensure high elasticity of joints, but they possess reduced fluidity and fill clearances poorly, and also require thorough trimming of the glued surfaces and relatively high specific pressures.

Table 34. Shear strength τ_B in kgf/cm^2 of glued joints at various temperatures [14].

Glue	Material	Temperature of tests in °C						
		−60	20	60	100	200	250	300
VK 3	Duralumin D16AT, anodized**	350	180	125	115	—	—	—
	Steel 30KhGSA, sand blasted	460	200	130	120	—	—	—
VK 32-200	Duralumin D16AT, anodized**	200	190	—	130	70	—	30
	Steel 30KhGSA, sand blasted	400	240	—	—	90	—	35
VK 32-250	Duralumin D16AT, anodized**	245	180	—	140	80	60	20
	Steel 30KhGSA, sand blasted	360	190	—	150	85	70	30
VK 4	The same	300	175	—	—	—	70***	55

* Liquid glues were used.
** Samples were destroyed basically with peeling of the anode film.
*** Tested at 275°C.

As can be seen from Table 23, the greatest elasticity is possessed by joints made with VK 3 glue. In respect to nonuniform breaking strength they exceed joints made with glues VK 1, KS 609, and approach those joints made with MPF 1 glue. Along with this, joints made with VK 3 glue also possess high thermostability. Thus, shear strength and nonuniform breaking strength of joints of Duralumin and steel carried out on this glue [14], does not diminish after the effect of constant temperature of 200°C for 1000 h and diminish insignificantly (10-15%) during the action of temperature variations from -60 to +80°C. This testifies to the high restivity of VK 3 glue to precipitation hardening during heating to 200°C and the cyclic effects of temperature variations, and also to its good frost-resistance. Therefore, VK 3 glue is recommended for power connections operating for a prolonged period (1000 h) during heating to 200°C.

Joints made with VK 3 glue are resistant to the effect of water, T1 fuel, gasoline, and oils. Direct action of water on the glued joint for 30 days caused a lowering of its strength by 15-25% (depending upon the test temperature).

Glues VK 32-200, VK 32-250, and VK 4 are more heat-resistant not only as compared to glue VK 3, but also with glues VK 1, VK 1MS, VK 7, and VK 9 (Tables 21-23 and 33). However, the thermostability of joints made with these glues is somewhat less, for example, than for joints with VK 3 glue. Thus, shear strength of joints made with VK 32-200 glue remains practically constant after the effect of a temperature of 200°C for only 300 h and a temperature of 300°C for 20-30 h. Joints made with glue VK 32-250 have higher strength indices at 250°C than those with glue VK 32-200 (Tables 22 and 34). Shear strength of joints made with glue VK 32-250 practically is unchanged after the effect of temperatures of 250-275°C for 300 h. Thus, in accordance with the given data, the heat resistance of glues VK 32-200 and VK 32-250 can be recommended for power connections operating for 300 h at temperatures of 200 and 250°C respectively and for 20-30 h at a temperature of 300°C.

Joints made with VK 4 glue yield in nonuniform breaking strength at a temperature of 20°C to joints made with glues VK 3, VK 32-200, and VK 32-250 (Table 23). However, they possess higher characteristics of short-term strength at 275-300°C (Tables 22, 23, and 34) and, according to [14], are capable of more prolonged operation (to 100 h) at 300°C. With VK 4 glue it is possible to join different steels, alloys of aluminum, titanium, and other metals, and also heat-resistant textolites of the VFT type.

Joints made with glues VK 32-200, VK 32-250, and VK 4 also possess high strength during vibration loads and are resistant to the action of oils, liquid fuel, water, and tropical climate. Thus, fatigue-strength during shear of steel joints made with VK 32-200 glue at 20°C is equal to 90 kgf/cm^2 (base of $13\cdot10^6$ cycles), at 250°C, 50 kgf/cm^2 (base of $10\cdot10^6$ cycles); with VK 32-250 glue at 20°C, 90 kgf/cm^2 (base of $6\cdot10^6$ cycles), at 250°C, 45 kgf/cm^2 (base of $8\cdot10^6$ cycles) and with VK 4 glue at 20°C, 80 kgf/cm^2 (base of $10\cdot10^6$ cycles), at 275°C, 65 kgf/cm^2 (base of $3.1\cdot10^6$ cycles) [1, 2].

The lowered fluidity of the described glues, the necessity of application of high specific pressures during their hardening, and also the lack of airtightness of the glued layer after its hardening do not permit recommending these glues for production of glue-welded joints. However, these glues in connection with their high heat resistance can be used with success for production of glue-riveted and glue-threaded joints in nonairtight articles operating at raised temperatures.

Glues VS 10T and VS 350 represent heat-resistant compositions on the basis of copolymers of polyvinylacetals, phenolic resins, and silicoorganic compounds. Besides this, into the composition of the glues there is also introduced a stabilizer – quinoline, delaying the process of thermal destruction. The heat resistance of these glues is ensured, on the one hand, by the density of space grid between molecular chains of polymers, on the other, – by the thermal and thermooxidizing resistance of the polymers. They are supplied in the form of uniform solutions of brown color without impurities.

Glues VS 10T and VS 350 possess good adhesion to metals (Duralumin, steels, and others) and nonmetallic materials (fiberglass laminates, foam plastics of the type FK, K 40, and others).

The VS 10T glues consists of a single-component system consisting of a solution of polyacetal, phenolformaldehyde resin and alkoxysilane in a mixture of organic solvents [11]. Concentration of the dry residue is 15-30%. Dilution of the glue by ordinary organic solvents is permissible. Viscosity thus can be changed over a wide range without changing the strength properties of the glued joints obtained. The glue can be stored in hermetically closed packing for nearly 6 months.

Glue VS 350 differs from glue VS 10T by the fact that it contains phenolformaldehyde-furfural resin [11], promoting an increase in the heat resistance of the glue composition.

Both glues are oil- and are benzine-resistant, and also resistant to organic solvents, are satisfactorily water-resistant, possess good fluidity and ability to fill clearances, can be used both in liquid form and also in the form of combination of them with films from fiber impregnated with liquid glue. However, in liquid form they do not produce uniform filling of clearance in the joint; furthermore, a great quantity of solvent leads to the formation of shrinkage porosity of the glue layer and lack of airtightness of the joint. This does not permit recommending them for production of glue-welded joints.

Along with the mentioned deficiencies, both glues possess marked fragility in the hardened state, the results of which are comparatively low strength during nonuniform breakaway (Table 23) and resilience of joints. It is recommended [11, 14] that the following conditions of gluing be used: glue VS 10T — temperature of preheating $180^{\circ}C \pm 5^{\circ}$; glue VS 350, $200^{\circ}C \pm 5^{\circ}C$; holding for both glues under a pressure of 0.6-5 kgf/cm^2 for 1-2 h.

As can be seen from Tables 22 and 35, joints made with glues VS 10T and VS 350 possess heat resistance up to a temperature of $350^{\circ}C$. Joints made with glue VS 350 have less strength at a temperature of $20^{\circ}C$ than the joints made with glue VS 10T, but are more thermoresistant and possess higher stress rupture strength during heating. Thus, shear strength of joints of steel on glue VS 350 remain practically constant after the effect of a temperature of $200^{\circ}C$ for 200 h, and $350^{\circ}C$ for 5 h. At the same time, shear strength of joints made with glue VS 10T after the effect of a temperature of $200^{\circ}C$ for 200 h drops 50% as compared to initial strength with the same temperature [14, 17]. Joints made with these glues possess high nonuniform breaking strength, especially with glue VS 350 ($S_{om} \approx 5-7$ kgf/cm at $20^{\circ}C$ versus 12 kgf/cm for VS 10T glue).

Fatigue-strength during shear of joints of steel 30KhGSA equals: on glue VS 10T at $20^{\circ}C$, 75 kgf/cm^2 (base of $1 \cdot 10^6$ cycles), at $200^{\circ}C$, 50 kgf/cm^2 (base of $5.2 \cdot 10^5$), at $300^{\circ}C$, 40 kgf/cm^2 (base of $1 \cdot 10^5$

cycles); on glue VS 350 at 200°C, 80 kgf/cm^2 (base of $5.8 \cdot 10^6$), at 350°C, 45 kgf/cm^2 (base of $1 \cdot 10^5$ cycles) [11, 12].

Table 35. Shear strength τ_B in kgf/cm^2 of joints made with liquid glues VS 10T and VS 350.

Glue	Material	Temperature of tests in °C								
		−60	20	60	100	150	200	250	300	350
VS 10T	Duralumin D16T, anodized..	106	123	121	—	98	87	—	48	—
	Steel 30KhGSA, sand blasted..................	143	196	180	160	147	90	70	65	21
VS 350	Duralumin D16T, anodized..	102	88	89	—	88	86	—	49	32
	Steel 30KhGSA, sand blasted..................	140	176	180	170	170	107	105	85	60

In accordance with the described properties, glues VS 10T and VS 350 can be recommended for production of power glued glue-riveted and glue-threaded joints in articles operating a prolonged time (up to 200 h) at a temperature of 200°C and short term (up to 5 h) at a temperature of 300°C (glue VS 10T) and at a temperature of 350°C (glue VS 350).

Glues VK 2, VK 6 and VK 8 consist of a composition on the basis of modified silicoorganic resin and a mineral filler (asbestos). These glues differ in high heat resistance (Table 36), therefore they are recommended for gluing of metals (steel, titanium, and aluminum alloys) and heat-resistant nonmetallic materials (siliconized graphite), asbestos cement, fiberglass laminate, molding material AG 4, and others), working at high temperatures. Along with this, the glues mentioned can also be used successfully for production of glue-threaded joints, especially for locking of bolts and screws.

The high heat resistance of these glues is caused by the high thermostability of the silicoorganic resin and the use of asbestos as a filler. However, the glues mentioned possess comparatively low plasticity in hardened state, therefore joints made with them

(especially with glue VK 2) have lower nonuniform breaking strength and lower impact toughness (Table 36), which, in a number of cases, essentially limits their field of application.

Table 36. Strength characteristics of glued joints of steel 30KhGSA at various temperatures.

Glue	τ_s in kgf/cm^2 at temperature of tests in °C							S_{om} in kgf/cm	Specific impact toughness in kgf/cm^2	Source
	−60	20	300	350	400	700	1000			
VK 2	75	90	56	53	48	43	29	7—9	0,5	[8]
VK 6	—	115—131	49—61	46—60	46—59	17—25*	13—18	10—11	—	[1]
VK 8	145	155	—	55	35	20	12	13—15	1,8	[8]
VS 350	140	—160	—	45	15	—	—	10—12	1,0	[8]

* Testing was conducted at 750°C.

These glues constitute ready liquid compositions with concentration of dry residue of 40-50%. Glue VK 2 hardens at a temperature of 240-275°C in 3 h, glues VK 6 and VK 8 – at a temperature of 200°C in 3 h and a molding force of 3-5 kgf/cm^2. This indicates that glues VK 6 and VK 8 are more technologic than VK 2. Viability of glues VK 2 and VK 8 is, 6 months; VK 6 – 2 months.

In Tables 36 and 37 strength characteristics are given for joints made with glues VK 2, VK 6, VK 8, and for comparison made with glue VS 350. As can be seen, these joints have comparatively low strength at a temperature of 20°C, however they preserve considerable strength at high temperatures (up to 700°C), exceeding in this respect all other glued joints being used at present in industry. The most heat-resistant are joints made with glue VK 2; however they markedly yield to joints, especially those made with glue VK 8, in static crack strength, vibration strength, and elasticity at room temperature.

Table 37. Shear strength τ_B in kgf/cm^2 of joints of different metals on glue VK 8 [9].

Material	Temperature of tests in °C	
	20	400
Steel 30KhGSA............	156	35
Titanium alloy VT 4......	170	24
Steel EI654..............	145	32
Steel 30KhGSA + fiber-glass laminate VFT.......	182	44

Joints made with VK 2 glue also have less stress rupture strength at 20°C than joints made with glues VK 6 and VK 8. Steel joints made with VK 2 glue can withstand for 1000 h without destruction a shear stress of 54 kgf/cm^2, with VK 6 glue, 103 kgf/cm^2, and with VK 8 glue for 1300 h, 120 kgf/cm^2. However, the thermostability of joints made with VK 2 glue is very high and exceeds the thermostability of joints made with glues VK 6 and VK 8. Thus, steel joints made with VK 2 glue preserve sufficient shear strength after holding at a temperature of 350-400°C for 300 h and more; under a stress of 10 kgf/cm^2 they are able to work without destruction at a temperature of 800°C for 100 h. Joints made with VK 6 glue are able to sustain without destruction a stress of 21 kgf/cm^2 at 425°C for only 5 h, and joints made with VK 8 glue under a stress of 12.5 kgf/cm^2 withstand the effect of a temperature of 400°C for 2 h.

Fatigue-strength during shear of joints of steel 30KhGSA at a temperature of 350°C on VK 2 glue is equal to 35 kgf/cm^2 (base of $3 \cdot 10^6$ cycles), on VK 6 glue 30 kgf/cm^2 (base of $3.2 \cdot 10^6$ cycles) [1]. Fatigue-strength of joints of steel 30KhGSA on VK 8 at a temperature of 20°C is equal to 100 kgf/cm^2 (base of $2.5 \cdot 10^6$ cycles), at 400°C, 20 kgf/cm^2 (base of $70 \cdot 10^3$ cycles), and at a temperature of 1000°C, 5.2 kgf/cm^2 (base of $37.4 \cdot 10^3$ cycles).

Joints made with glues VK 2, VK 6, and VK 8 are resistant to the effect of gasoline, mineral oil, and T1 fuel. Furthermore, they are sufficiently water- and tropic-resistant, do not cause corrosion of stainless steels and alloys of titanium. For example, after the effects of water for 1 month, the strength of joints made with VK 8 glue [9] decreases at 20°C only by 5%, at 400°C – by 10-12%. After holding these joints in a tropical chamber for 30 days their strength was not changed.

Thus, in accordance with examined data, the heat resistance of glues VK 2, VK 6, and VK 8 can be recommended for glued and glue-threaded joints operating: with glue VK 2 at a temperature of 350°C to 1000 h, at 400°C to 250 h, at 1000°C to 5 min; with glue VK 6 at 425°C to 4 h, at 750°C, 5 min, at 1000°C, 2 min; with glue VK 8 at 350°C up to 24 h, at 400°C up to 5 h, at 1000°C, 5 min.

Footnotes

[1]Author's certificate No. 138301 from 8/VIII 1961. Certificate is issued to V. P. Bochkarev and others.

[2]The glue was developed in NIIPM by R. Ya. Fishina and others.

CHAPTER II

CERTAIN QUESTIONS ON THE TECHNOLOGY OF RESISTANCE SPOT WELDING OF ALUMINUM ALLOYS

General Information

In structures prepared by means of resistance spot welding, basically deformable aluminum alloys are used in the form of a pressed profile sheet. Basic weldable alloys of aluminum and some of their physical and mechanical properties are given in Table 38.

Resistance spot welding is used to perform power and nonpower lap and strap joints. In spot welding of aluminum alloys for production of high-quality joints it is necessary to have stability in the basic parameters of welding conditions (force of compression of electrodes, welding current, and duration of its flow) and sufficiently high-quality preparation of the surface of the parts being welded.

A feature of the thermophysical and mechanical properties of aluminum alloys requires, for production of high quality joints, somewhat increased dimensions of overlap (as compared to steel constructions), distance of points from vertical walls of profiles or edge of overlap, and interval between points (Table 39). A necessary condition is paneling of the structure and open bilateral approach, ensuring the possibility of welding by electrodes of simple geometric form, preferably straight and well cooled.

Table 38. Some physical and mechanical properties of aluminum weldable alloys.

Material	State of material	ρ in $\frac{\Omega\ mm^2}{m}$	λ in $\frac{cal}{\Omega\ s}$ °C	δ in %	$\sigma_{0.2}$ in kgf/mm^2	σ_B in kgf/mm^2	Alloy system
ADM and AD1M	Annealed	0.028	0.54	20	—	11	—
AD0, AD1N	Cold hardened	0.029	0.52	4	—	15	—
AMtsAM	Annealed	0.035	0.037	22	5	13	Al — Mn
AMtsP	Semi-cold hardened	0.042	0.38	10	13	17	Al — Mn
AMtsT	Cold hardened	0.130	—	2	—	32	Al — Mn
AMgAM	Annealed	0.047	0.37	17	10	17—23	Al — Mg
AMg3M	"	0.049	0.35	22	10	20	Al — Mg
AMg5VM	"	0.064	0.29	23	15	28	Al — Mg
AMg6M	"	0.071	0.28	24	10	32—34	Al — Mg
AVT1	Hardened and naturally aged	0.05	0.4	10	—	30	Al — Mg — Si
AMg6N	Cold hardened	0.071	0.28	15—16	18	38—39	Al — Mg
AT	Hardened and artificially aged	0.055	0.37	8—10	—	30	Al — Mg — Si
AD31	The same	0.034	0.45	10	19	23	Al — Mg — Si
AD33	"	0.043	0.34	10	24	29	Al — Mg — Si
M40	"	0.061	0.29	8—17	24—30	38—40	Al — Cu
M4	Annealed	—	—	17	—	26	Al — Cu
M2C	"	—	—	20	—	25	Al — Cu — Mn
D2	Hardened and artificially aged	0.061	0.33	8	28	38	Al — Cu — Mn
D16AM	Annealed	0.047	0.41	10	—	23	Al — Cu — Mg
D16AT	Hardened and artificially aged	0.073	0.28	12	28	41—43	Al — Cu — Mg
V95AT	The same	0.059	0.37	7	41—44	49—52	Al — Zn — Mg — Cu
V92	"	—	—	22	29	43	Al — Zn — Mg
V92	Hardened and naturally aged	—	0.32	19	22	38—39	Al — Zn — Mg
VAD17	The same	0.059	0.28	13—12	27—31	40—41	Al — Cu — Mg
D19	"	0.061	0.31	20	30	42—44	Al — Cu — Mg
ATsM	Hardened and artificially aged	—	—	12	38	45	Al — Zn — Mg
VAD23	The same	0.091	0.23	4	49—50	54—55	Al — Cu — Mn — Li — Cd
SAP1	Rolled sheet	0.042	0.4	3—10	—	30—40	Sintered aluminum powder
AMtsM1	Cold hardened	0.112	—	2	—	32—33	Al—Mn

Table 39. Recommended dimensions of spot joints made from aluminum alloys in mm.

Thickness of thinner part in the joint	Diameter of nucleus spot	Minimum dimensions: Lap: Seam single-row	Minimum dimensions: Lap: Seam double-row	Minimum dimensions: Interval between spots	Thickness of thinner part in the joint	Diameter of nucleus of spot	Minimum dimensions: Lap: Seam single-row	Minimum dimensions: Lap: Seam double-row	Minimum dimensions: Interval between spots
0,3	2,5—3,5	8	15	8	2	7—8	20	42	25
0,5	3—4	10	18	10	3	9—10	26	58	35
0,8	3,5—4,5	12	25	13	4	12—14	30	70	45
1	4—5	14	28	15	5	14—16	36	84	55
1,2	5—6	16	30	15	6	16—18	42	98	65
1,5	6—7	18	35	20	7	17—19	46	110	75

It is not recommended (especially in power constructions) to weld three parts and more in a pack. The ratio of thicknesses to be welded should not exceed 3:1.

In the manufacture of welded subassemblies it is necessary to perform adjacent operations on which the quality of welded joints depends; assembly, marking, clamping, etc. For spot welding, the clearance between mating parts should be minimum, uniform, and not more than 0.1-0.5 mm (depending upon thickness and dimensions of the parts) and easy to remove with application of insignificant force.

In experimental and small-lot production usually is made a preliminary docking assembly, carried out prior to preparation of the surface. The billets collected in the dock are bored jointly in the places for setting of the assembling bolts, they are disassembled and pass on a set to the section for preparation of the surface.

In series production it is recommended that there be used the advanced method of assembly by base holes, with which the parts with preliminarily bored base holes are transmitted in batches after preparation of the surface for final assembly before welding.

Marking the places for location of weld spots in accordance with the drawing is carried out with hard pencil with a marking

rule or with an applied template. Marking by a metallic scriber is not allowed. When, use is made of optical markers set on the welding machines, preliminary marking can be excluded.

Clamping is necessary to give the collected parts rigidity and to decrease warping during welding. Clamping is carried out, as a rule, in an assembly jig, fixing the contour of the part. The clamping interval usually is set within limits of 200-300 mm. Clamping is performed along the axial line of the seam, combining the clamped points with places of location (according to the plan) of weld spots. The conditions of clamp should without fail be identical to the welding.

Preparation of the Surface

The process of surface preparation of parts to be welded consists in removal from it of protective lubrication, contaminated and oxide film, in obtaining over the entire surface to be welded a stable and insignificantly large (on the order of 20-120 $\mu\Omega$) electrical resistance contact and in preservation of the constancy of this resistance as long as possible.

The surface of parts to be welded can be prepared by the following methods: 1) mechanical stripping (manually with help of emery paper or steel wire brush); 2) chemical etching. The latter method is the most convenient and modern and therefore is widely used not only in series, but also in experimental production.

Before chemical etching it is necessary to remove from the surface of the parts reference marks, protective lubrication, and contamination by means of brushes or rags moistened in organic solvents (gasoline, acetone, etc). Then the part is placed in an alkali bath for final degreasing.

Solutions during treatment must be heated to 60-70°C and mixed by compressed air. Degreasing takes 3-5 minutes. Degreasing

is allowed in other alkali solutions with general alkalinity up to 6% (converted to sodium hydroxide). Degreasing in autoclaves filled with vapors of trichlorethylene or tetrachlorethylene is widely used abroad. After degreasing, the parts are thoroughly washed for 1-2 min in warm running water with a temperature of 50-60°C and then in a bath with cold water.

Chemical etching of parts is used for the purpose of removing from their surface the relatively thick film of γ phase, with high and nonuniform electrical resistance, formed in the process of hot working of rolling, heat treatment (of aluminum alloys such as duralumin). This film prevents the process of spot welding of the metals mentioned. After chemical etching, on the surface of the parts there will be formed a film of ε phase, which is thinner, with low and sufficiently uniform electrical resistance, which with the passage of time acquires the electrical properties of γ phase film. To avoid rapid accretion of film in atmospheric conditions, in the composition of the pickling solution there are introduced passivating elements, retarding the process of accretion of oxide film. The oxide film forming on the surface of aluminum alloys of the Al-Mg system differs somewhat in composition and structure from the described film, however the essence of the removal process by chemical etching is analogous.

Etching with passivation is produced in solutions of orthophosphoric acid of various compositions. The most widely used in production is a solution with the following composition: 110-115 g/l of orthophosphoric thermal acid; 1.5-0.8 g/l of technical potassium dichromate; the rest is water. Minimum duration of this process at a temperature of solution of 40°C is 10 min, at 50°C, 7 minutes.

Washed parts are dried at a temperature no higher than 60°C, and prior to welding are thoroughly protected against exposure to moisture and contamination.

In experimental works and custom production in separate cases mechanical stripping of the surface of parts is allowed in places of welding after degreasing of the parts. This stripping must be done, as a rule, with a revolving wire brush mounted on a pneumatic hand brace. Diameter of the brush is usually 120-150 mm, the diameter of the wires (cold hardened) steel is not more than 0.2 mm. The length of the part of wire which is loose in mandrel should not be less than 40-50 mm. The recommended number of revolutions of the brush during stripping is 2000-2500 per minute. Speed of the brush over the article is 60-75 mm with a force of not more than 1.5-2 kgf.

Mechanical stripping is inevitable during repeated welding in case of correction of defective spots or during accidental interruption of the welding process exceeding in duration the maximum permissible after chemical etching.

Quality control in the preparation of the surface is produced by measurement of contact (transition) electrical resistance of the parts being combined, being performed on a special SKKS-1 stand (Fig. 1) on lapped control samples. The amount of resistance is measured by an M246 micro-ohmmeter or other of low resistance should not exceed 120 $\mu\Omega$ during the entire welding cycle of the parts.

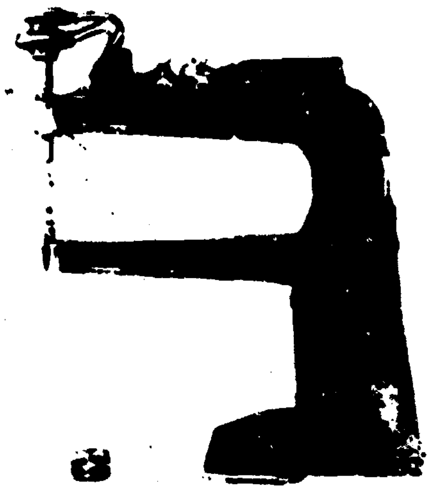


Fig. 1. Stand for measurement of contact resistance, SKKS1.

All operations connected with chemical preparation of parts before welding must be performed in specially equipped isolated locations. Parts prepared for welding are grouped and sent to the welding section for clamping and welding.

Selection of Welding Conditions

It is basic in selecting welding conditions to establish the most favorable program of heating (form and pulse width of welding current) and change in the force of compression of electrodes after the welding cycle, taking into account the characteristics of the available equipment and the thermophysical properties of the material being welded. Under optimum conditions there must be ensured the best conditions for formation of the welded joint and its high strength. Insignificant arbitrary deviations in it should not affect the quality of welding.

Engineering methods for calculation of optimum conditions and welding conditions do not exist, therefore rational conditions are selected experimentally. Selected approximate conditions are checked during welding of technological test samples and corrected where necessary. To a very considerable degree, conditions depend on the physical and mechanical properties of the alloys being welded (first of all on specific electrical resistance and yield point). In accordance with this, aluminum alloys can be split into two basic groups: group I – alloys D16T, D20T, M40, V95T, AMg6, and similiar to them, $\sigma_{0.2}$ = 16-42 kgf/mm^2; ρ = 0.06-0.07 $\Omega \cdot mm^2/m$ (see Table 38); group II – alloys D16M, D20M, AMg, AMts, etc.

At present, for each group of alloys depending upon combination of thicknessess being welded there can be recommended a cyclogram of optimum conditions (Table 40) and their parameters (Tables 41-43) [11]. Experimentally developed conditions ensure production of high-quality joints with dimensions shown in Table 39. For single-phase alternating current machines in the tables there is shown the effective value of welding current, for low-frequency and capacitor machines – peak value.

Table 40. Cyclograms of spot welding conditions of aluminum alloys.

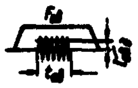
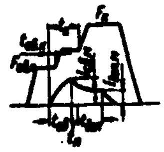
No. of conditions	Character of change of force and current	Type of welding machine	No. of conditions	Character of change of force and current	Type of welding machine
1		Single-phase alternating current	6		Three-phase low-frequency
2		The same	7		The same
3		»	8		»
4		»	9		Capacitor
5		Three-phase low-frequency	10		The same

Table 41. Approximate conditions for spot welding of aluminum alloys on low-frequency machines (series MTIP and MTPT).

Thickness of parts in mm	No. of conditions (see Table 40)	Group I alloys										Group II alloys						Remarks
		Parameters of force of compression of electrodes					Current parameters					No. of conditions (see Table 40)	Parameters of force of compression of electrodes			Current parameters		
							Main pulse		Supplementary pulse									
		Initial welding $F_{cв.н}$ and $(F_{cв})$ in kgf	Final welding $F_{cв.к}$ in kgf	Increase of welding force $t_{cв.к}$ in s	Forging $F_к$ in kgf	Turning on forging force $t_к$ in s	Amplitude $I_{cв}$ in kA	Duration $t_{cв}$ in s	Beginning of pulse $t_м$ in s	Duration of t in s	Amplitude $I_{ocв}$ in kA		Welding $F_{cв}$ in kgf	Forging $F_к$ in kgf	Turning on of forging force $t_к$ in s	Amplitude $I_{cв}$ in kA	Duration $t_{cв}$ in s	
0,8+0,8	6	350	—	—	500	0,06	26	0,04	—	—	—	5	200	—	—	25	0,04	Rigid conditions
1+1	6	400	—	—	800	0,06	29	0,04	—	—	—	5	250	—	—	29	0,04	
1,5+1,5	6	500	—	—	1 400	0,08	41	0,06	—	—	—	5	350	—	—	35	0,06	
2+2	6	700	—	—	1 900	0,12	50	0,1	—	—	—	5	500	—	—	45	0,1	
2,5+2,5	6	900	—	—	2 600	0,16	59	0,14	—	—	—	5	650	—	—	49	0,14	
3+3	6	1200	—	—	3 200	0,2	64	0,16	—	—	—	6	800	2200	0,2	57	0,16	
3,5+3,5	6	2000	—	—	4 400	0,26	72	0,18	—	—	—	6	900	2400	0,24	65	0,18	
4+4	6	2800	—	—	6 000	0,28	85	0,2	—	—	—	6	1000	2600	0,26	72	0,2	
5+5	7	1500	4500	0,1	8 700	0,38	130	0,26	0,1	0,16	60	—	—	—	—	—	—	
6+6	7	2200	6600	0,12	11 500	0,44	155	0,3	0,12	0,2	70	—	—	—	—	—	—	
7+7	7	2750	7000	0,14	15 000	0,52	170	0,36	0,14	0,2	75	—	—	—	—	—	—	
0,5+0,5	8	200	—	—	—	—	20	0,02	—	0,04	12	—	—	—	—	—	—	
0,8+0,8	8	300	—	—	700	0,06	25	0,04	—	0,08	15	—	—	—	—	—	—	
1+1	8	400	—	—	800	0,08	29	0,04	—	0,08	18	—	—	—	—	—	—	
1,5+1,5	8	500	—	—	1 100	0,12	40	0,06	—	0,12	20	—	—	—	—	—	—	
2+2	8	800	—	—	1 800	0,14	55	0,08	—	0,16	25	—	—	—	—	—	—	
2,5+2,5	8	1200	—	—	2 800	0,18	64	0,1	—	0,2	32	—	—	—	—	—	—	
3+3	8	1500	—	—	3 600	0,2	73	0,12	—	0,24	37	—	—	—	—	—	—	
1,5+1,5	6	400	—	—	1 000	0,16	31	0,12	—	—	—	—	—	—	—	—	—	Mild conditions
2+2	6	600	—	—	1 600	0,24	34	0,2	—	—	—	—	—	—	—	—	—	
2,5+2,5	6	800	—	—	2 200	0,28	40	0,24	—	—	—	—	—	—	—	—	—	
3+3	6	1000	—	—	3 000	0,34	45	0,28	—	—	—	—	—	—	—	—	—	
3,5+3,5	6	1600	—	—	4 000	0,4	52	0,3	—	—	—	—	—	—	—	—	—	
4+4	6	2100	—	—	5 300	0,46	60	0,36	—	—	—	—	—	—	—	—	—	

Table 42. Approximate conditions of spot welding of aluminum alloys on single-phase alternating current machines.

Thickness of parts in mm	Group I: No. of conditions (see Table 40)	Group I: Parameters of force of compression of electrodes: Welding $F_{св}$ in kgf	Group I: Parameters of force of compression of electrodes: Forging $F_к$ in kgf	Group I: Parameters of force of compression of electrodes: Turning of forging force $t_к$ in s	Group I: Current parameters: Effective value of $I_{эф.д}$ in s	Group I: Current parameters: Duration in s: of accretion $t_н$	Group I: Current parameters: Duration in s: of welding $t_{св}$	Group I: Current parameters: Duration in s: of drop $t_{сп}$	Group II alloys: No. of conditions (see Table 40)	Group II alloys: Parameters of force of compression of electrodes: Welding $F_{св}$ in kgf	Group II alloys: Parameters of force of compression of electrodes: Forging $F_к$ in kgf	Group II alloys: Parameters of force of compression of electrodes: Turning of forging force $t_к$ in s	Group II alloys: Current parameters: Effective value of $I_{эф.д}$ in kA	Group II alloys: Current parameters: Pulse width $t_{св}$ in s
0,5+0,5	1	220	—	—	17	—	0,08	—	1	130	—	—	16	0,08
	3	200	—	—	16	0,04	0,08	0,12	—	—	—	—	—	—
0,8+0,8	1	350	—	—	19	—	0,1	—	1	190	—	—	18	0,1
	3	300	—	—	18	0,04	0,1	0,14	—	—	—	—	—	—
1+1	1	450	—	—	24	—	0,12	—	1	250	—	—	22	0,12
	3	350	—	—	23	0,04	0,12	0,14	—	—	—	—	—	—
1,5+1,5	1	650	—	—	30	—	0,16	—	1	350	—	—	27	0,14
	3	550	—	—	29	0,06	0,16	0,16	—	—	—	—	—	—
	4	450	1000	0,24	27	0,06	0,16	0,16	—	—	—	—	—	—
	2	450	1200	0,18	28	—	0,16	—	—	—	—	—	—	—
2+2	1	600	—	—	35	—	0,2	—	1	500	—	—	32	0,18
	3	700	—	—	33	0,08	0,2	0,18	2	400	1000	0,22	30	0,18
	4	650	1200	0,32	31	0,08	0,2	0,18	—	—	—	—	—	—
	2	650	1500	0,24	32	—	0,2	—	—	—	—	—	—	—

Table 43. Approximate conditions of sp[illegible] [illegible]ld-ing of aluminum alloys on capacitor machines (type MTK75).

Thickness of parts in mm	Group I alloys								
	No. of conditions (see Table 40)	Force of compression of electrodes: Welding P_{ce} in kgf	Force of compression of electrodes: Forging P_{κ} in kgf	Force of compression of electrodes: Turning on forging force t_{κ} in s	Welding current I_{ce} and kA	Pulse width in s: t	Pulse width in s: T	Voltage of capacitor in V	Capacity of battery in microfarads
0,3+0,3	9	120	—	—	16	0,006	0,021	360	8 400
0,5+0,5	9	200	—	—	20,5	0,012	0,027	320	16 800
0,8+0,8	10	300	500	0,034	27,5	0,014	0,039	360	25 200
1+1	10	400	800	0,041	30,5	0,018	0,046	340	33 600
1,5+1,5	10	600	1400	0,065	48	0,026	0,068	360	84 000
2+2	10	800	2100	0,084	55	0,028	0,074	380	109 200
2,5+2,5	10	1000	3000	0,127	67	0,038	0,104	400	176 400

Thickness of parts in mm	Group II alloys								
	No. of conditions (see Table 40)	Force of compression of electrodes: Welding P_{ce} in kgf	Force of compression of electrodes: Forging P_{κ} in kgf	Force of compression of electrodes: Turning on forging force t_{κ} in s	Welding current I_{ce} in kA	Pulse width in s: t	Pulse width in s: T	Voltage of capacitor in V	Capacity of battery in microfarads
0,3+0,3	9	80	—	—	15	0,006	0,021	340	8 400
0,5+0,5	9	120	—	—	20,5	0,012	0,027	320	16 800
0,8+0,8	9	190	—	—	28	0,018	0,046	320	33 600
1+1	9	250	—	—	32,5	0,019	0,05	340	42 000
1,5+1,5	9	400	—	—	44	0,024	0,034	360	67 200
2+2	10	550	1000	0,084	54	0,026	0,078	380	100 800
2,5+2,5	10	700	1400	0,118	65	0,032	0,1	400	168 000

Note: [illegible]ransformation ratio 40.

Equipment and Electrodes

Inasmuch . . .uminum alloys possess high thermo- and electrical conductivity (Table 38), current density in the welding contact should equal 1000-1100 A/mm^2 and more, which requires the use of powerful welding equipment ensuring short-term and at the same time welding current of great amplitude pulses. Machines used for spot welding of these alloys are subdivided in respect to power criteria into three basic types: single-phase alternating current modulated and unmodulated pulses, and three-phase low-frequency with ignitron converters, with accumulation of energy in an electrical or magnetic field.

Single-phase machines (alternating current). Domestic industry is producing large number of types and dimensions of single-phase machines for spot welding of structural steels (series MTP, with power of 75-400 kVA) [2, 6].

In order to guarantee quality welding of aluminum alloys, machines of the MTP series must be equipped with a device for creation of forging force for the electrodes and must connect to a breaker of PIT type of electronic modulator. In the presence of a reserve of induction of the core of the welding transformer it is possible to increase short-term power by connection of a booster transformer or by decreasing the number of turns in the primary winding of the transformer. However, the MTP machine is not recommended for use in welding of important high-loaded structures made from aluminum alloys.

For spot welding of light alloys, alternating current machines MTPR 600, MTP 300A and MTPU 300 have been designed, fitted with synchronous electronic breakers with stabilization and modulation of the welding current. The basic technical data of these machines are given in Table 44.

Table 44. Basic technical data for single-phase machines for spot welding of aluminum alloys.

Indices	Type of machine		
	MTPR600	MTPU300	MTP300A
Thickness of welded parts in mm	From 0,3+0,3 To 1,5+1,5	From 0,5+0,5 To 1,5+1,5	From 0,5+0,5 To 1,5+1,5
Rated power in kVA	300	600	300
Limits of adjustment of compression of electrodes in kgf	80—1500	180—850	150—800
Sweep of electrodes in mm	500	900—1200	500
Distance between cantilevers (span) in mm	140—300	200—600	300—450
Rated tempo of work (points per minute)	40	30	40
Movement of upper electrode in mm			
working	15	10	15
additional	75	120	75

The machine MTPR 600 has a cantilever-power mechanism of radial type with a rocking upper bracket, which facilitates welding of three-dimensional structures of complex form. In the machine, provision is made for adjustment of the sweep and spacing of electrodes over a wide range. A large sweep for the electrodes permits welding large dimension structures with it.

In the MTP 300A machine, between the penumatic cylinder and the slider of the electrode compression drive there is placed an intermediate buffer with an auxiliary diaphragm. During a working movement after stopping the upper electrode in the part, the lower piston continues to be lowered and, moving 8-12 mm, it descends to the bottom of the cylinder. The diaphragm of the buffer from extreme bottom part moves the same distance to a middle position. Force of the electrodes is determined by air pressure in the super-diaphragm chamber. A similar design of the drive ensures high mobility of the upper electrode and constancy of force in the process of welding.

Forging force in machines MTPR-600 and MTP-300A is not provided for. The most universal machine is the MTPU 300. Thanks to wide adjustment of secondary voltage (1:4), the machine has a great

range in values of welding current, which permits welding, besides light alloys the upper control range of voltages is used (9-16 steps of switching on of transformer).

The pneumatic drive system of the MTPU 300 machine permits welding with constant and variable forces of electrode compression. The ratio of forging force to welding is equal to 2.35 and is maintained constant independently of the absolute value of the force. Air to the chamber above the piston and under it is supplied under identical pressure and is regulated by one reduction valve. Thanks to this, welding force during forge welding is maintained more stably than in systems with separate regulation of air pressure in the chambers.

Force is transmitted from the piston to the slider through set of plate springs, which permits eliminating jamming of the movable parts of the drive, ensures shift of the upper electrode in the process of thermal deformations of welded elements independently of the shift of the piston without change in the force of compression of electrodes. Shift of the rod with respect to the slider by the amount of setting of the springs permits an additional controlling force of compression of the parts.

Roller guides and a light Silumin slider practically eliminate the effect of forces of friction and mass of movable parts on the amount of compression force. The forging force, thanks to a high speed exhaust valve in the pneumatic system grows after a very short interval of time (0.01-0.02 s depending upon the volume of the chamber).

A breaker of the type ShU 123 ensures automatic stabilization of voltage of the welding transformer, pulse modulation of welding current, and supply for one cycle of welding of two current pulses, adjustable independently in respect to magnitude and duration.

Single-phase machines, as an electrothermal device intended for heating of the parts during welding of light alloys has rather

low efficiency. The economic expediency of using single-phase machines as compared to machines of other types (for example, low-frequency) is determined by taking into account the concrete operating conditions. Experience shows that single-phase machines for welding of parts with a thickness up to 1.5 + 1.5 mm with a 500-800 mm electrode sweep can compete with machines of other types. For welding of parts of great thicknesses (more than 1.5 + 1.5 mm) or great overall dimensions, because of the too great power required it is inexpedient to use single-phase machines.

Three-phase low-frequency machines with ignitron converters. At present, low-frequency machines are the most applicable for welding aluminum alloys. Welding is carried out by unipolar current pulse, passing through the welding contour with the switching on of a three-phase ignitron rectifier on the primary winding of a single-phase welding transformer. The welding current pulse thus obtained has the most favorable form for welding of metals and alloys which are inclined to crack formation. The smooth rise of current pulse (Fig. 2) to peak value ensures preliminary preheating and preparation of the welding contact, and the slow drop promotes elimination of crystallization cracks. In the latest modifications of machines of this series the control circuit makes possible the transmission of additional current pulse.

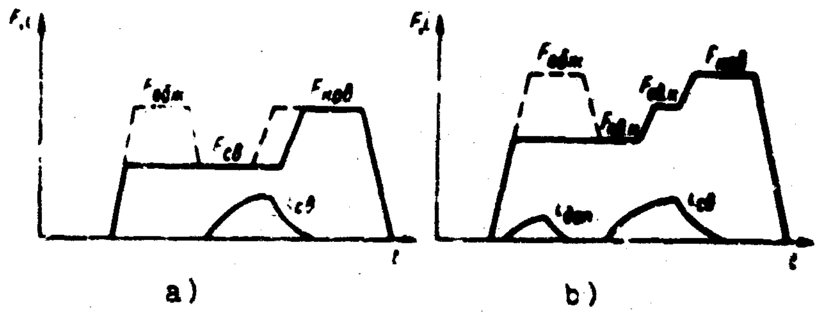


Fig. 2. Cyclogram of operation of low-frequency machines MTIP and MTPT: a) cycle with one current pulse and constant welding force; b) cycle with two current pulses and variable welding force.

The most well-known three-phase low-frequency machines are of the type MTPT 400 (Fig. 3), MTPT 600, MTIP 1000. Furthermore, in enterprises there are in operation a considerable number of earlier MTIP 300, MTIP 450, and MTIP 600 machines (Table 45). Elements of the control circuit and power rectifier are mounted in a separate cabinet [2, 6].

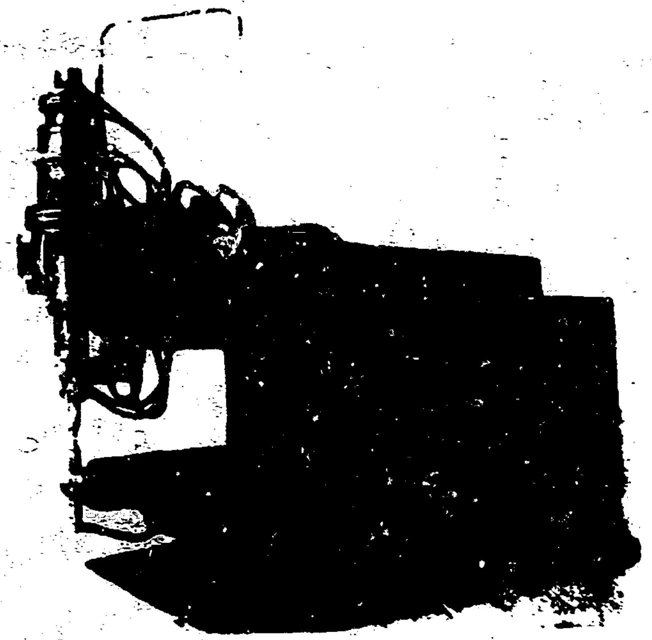


Fig. 3. Three-phase low-frequency MTPT 400 machine.

Table 45. Basic technical data of three-phase low-frequency machines for spot welding of aluminum alloys.

Indices	MTIP 300	MTIP 450	MTIP 600
Thickness of parts to be welded in mm	From 0,8+0,8 To 2,5+2,5	From 1+1 To 3+3	From 1,5+1,5 To 4+4
Rated power in kVA	300	450	600
Maximum welding current at rated power in kA	54,5	67,5	82,5
Maximum force of electrodes in kgf:			
welding	1150	1550	1800
forging	2600	2800	5000
Sweep of electrodes in mm	1200	1200	1200
Distance between cantilevers in mm	400	400	500
Movement of upper electrode in mm:			
working	15	15	15
additional	130	130	130

Table 45. (Cont'd).

Indices	MTPT 400	MTPT 600	MTIP 1000
Thickness of parts being welded in mm	From 0,8+0,8 To 3+3	From 1,5+1,5 To 4,5+4,5	From 3+3 To 7+7
Rated power in kVA	400	600	1 000
Maximum welding current at rated power in kA	73,5	102	160
Maximum force of electrodes in kgf:			
welding	1500	2600	9 000
forging	3500	7500	17 500
Sweep of electrodes, in mm	1500	1500	1 500
Distance between cantilevers, in mm	500	650	650
Movement of upper electrode, in mm:			
working	30	30	30
additional	300	300	130

The pneumatic drive of machines of the MTPT and MTIP series is three-diaphragm and low-inertia consecutive action. Its operation ensures following variants of welding cycles (Fig. 2): 1) with constant electrode force; 2) with forging, with which the force of the electrodes after 0.01-0.06 s grows from $F_{cв}$ to $F_к$; moment of application of forging force with respect to welding current pulse is regulated over a wide range, ensuring the possibility of producing a high-quality molten point nucleus; 3) with preliminary pressing $F_{обж}$ of the welded parts and with forging.

Machines MTPT 600 and MTIP 1000 can ensure a step graph of change of welding force within limits of the cycle, which expands even more their technological possibilities in the welding of parts of great thickness (Fig. 2b). Machine of the MTPT series have a mechanical drive for adjusting shift and a pneumatic drive for the working stroke of the upper electrode. The large adjusting movement (up to 300 mm) permits introducing into the contour of the machine large dimension articles of complex form. At any moment in the adjusting movement, the electric motor can be turned off and travelling parts of the drive stopped.

Domestic and foreign operational experience with three-phase machines with ignitron converters shows that they are the most expedient for use in welding of parts with a thickness of more than

1.5 mm, with an electrode sweep of more than 500 mm. In this case, their power advantage over the single-phase is especially essential. On the average, under equal conditions, the three-phase low-frequency machine consumes approximately 3-6 times less power than the single-phase. In certain cases, for example during very short durations of transmission of current, power is approximately equal, and the advantage consists only in equal distribution of load on three phases and the unipolar character of the welding current pulse.

A deficiency in low-frequency machines is the necessity to use bulky and heavy welding transformers and very complex control circuits.

Machines with accumulation of energy. In spot welding a great part of the full cycle duration is expended on such operations (raising and lowering of electrodes, shift of parts, etc.) during which energy is not expended on heating of the parts to be welded. If between the circui and the welding contour of the machine there is set a device, which in the intervals between weldings can consume energy from the net, can store it and return it to the contour in separate pulses, then by increasing the time of power consumption, the power of the system can be considerably reduced. The slowly occurring charging of the corresponding device is easy to control so as, in spite of oscillations of line voltage, to ensure constancy of accumulated energy.

Investigations made by different countries have developed a whole series of schematic diagrams for machines, using for welding, the energy stored in the electrical field of capacitors, the magnetic field of cores of transformers, electrochemical batteries, revolving masses, etc. Practical industrial application has been found for the circuit using an accumulation of energy in the electrical field of capacitors with subsequent discharge of them through a step-down transformer on the welding contour.

In condensing batteries of machines produced up to recent times paper capacitors were used with charge voltage of 3000-6000 V.

This permitted storing the necessary energy in small volume batteries; however, the high voltage required special safety engineering measures. Control circuits of these machines did not ensure control of form and pulse width of the welding current. Excessively steep front of build-up of welding current and short-term nature of the pulse complicated selection of optimum conditions.

In connection with the high-voltage mentioned electrostatic machines were used to an extremely limited extent.

At present machines of the MTK series are being developed with electrolytic capacitors, the operating voltage of which does not exceed 400 V, which makes it possible to service it just as an ordinary industrial power plant (Table 46). The mechanical parts of the MTK 75 and MTPT 400 machines are analogous. The MTR 1 machine has radial movement of electrodes from a rocking upper cantilever facilitating welding of articles of complex form (Fig. 4).

Table 46. Basic technical data of electrostatic machines for spot welding of aluminum alloys.

Indices	MTK [illegible]	MTK 75	MTR 1
Thickness of parts to be welded in mm	From 0,5+0,5 To 2+2	From 0,8+0,8 To 2,5+2,5	From 0,3+0,3 To 1,5+1,5
Rated power in KVA	40	75	10
Maximum force of compression of electrodes in kp:			
welding	800	2000	1000
forging	2000	4000	—
Sweep of electrodes in mm	1200	1500	1200
Distance between cantilevers in mm	500	500	350—500

Control circuits of the low-voltage electrostatic machines permit welding aluminum alloys in thickness from 0.3 + 0.3 to 2.5 + 2.5 mm by rigid pulses and relatively soft (according to duration commensurable with pulses of low-frequency machines), with smooth build-up of welding current. The guarantee of a wide control range of pulse width of welding current and its form made it possible for the first time in condensing machines to use a cycle of compression of electrodes with forging force (Fig. 5).

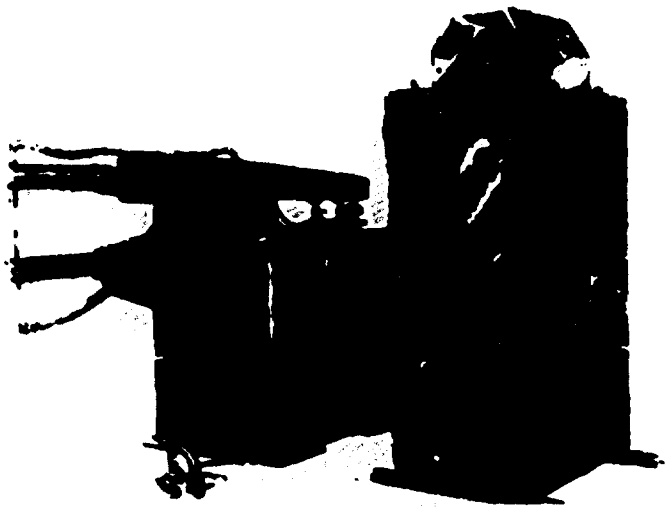


Fig. 4. Electrostatic welding machine MTK 1.

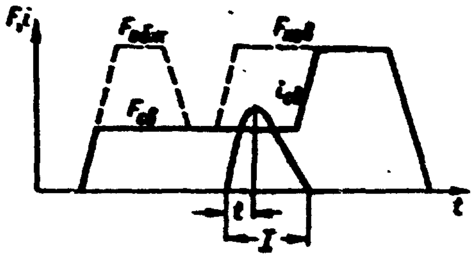


Fig. 5. Cyclogram of work of electrostatic machines MTK and MTR.

The wide control range of parameters of adjustment and the use of accumulation of energy permits sharply reducing the power consumed from the system. Thus, for example, at a rate of 40 pulses per minute and accumulation of energy ~22 kW·s (necessary for welding of an aluminum alloy with a thickness of 2.5 + 2.5 mm) maximum power drain amounts to 75 kVA. For comparison it can be pointed out that a three-phase low-frequency machine with equal sweep of electrodes (1500 mm) for welding of the same articles consumes 300-400 kVA, and single-phase alternating current — near 1500 kVA.

Besides reduction of the power drain, a very important advantage of the electrostatic machines is the independence of value of welding

current pulses from oscillation of line voltage, ensuring high stability in the quality of welded joints. Therefore, spot electrostatic machines are very promising for application in different branches of machine building.

In connection with appearance of new high-strength alloys (Table 38) and rational constructive solutions there appeared a tendency to decrease the thicknesses of sheathings in frame constructions. However, the series equipment widely used in industry was not in a state to ensure high-quality welding of materials with a thickness of less than 0.8 mm. The only one useful for welding of parts with a thickness of 0.3-1.0 mm is the MTR 1 machine, which as yet is being produced according to individual orders which clearly does not satisfy the growing needs of industry.

Machines of the MTPT and MTK series have a weight of movable parts of the compression drive of the electrodes exceeding the necessary values of force of compression for welding of parts with a thickness of less than 0.8 mm. For expansion of the technological possibilities of machines of this type, there have been developed small-dimension welding torches of type GT 3M (Fig. 6). These heads have individual low-inertia two-stage pressure drive, allowing welding of a part 0.3-0.8 mm thick.

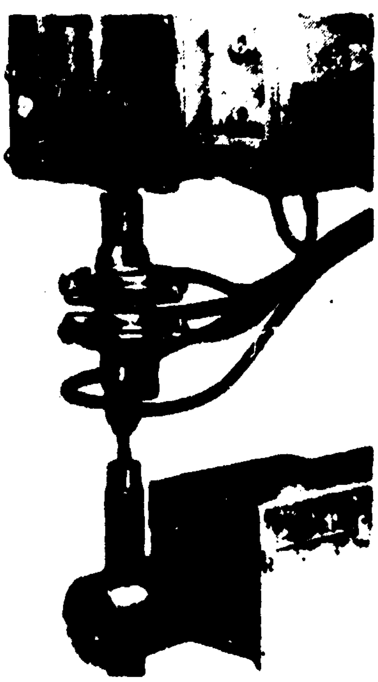


Fig. 6. Auxiliary pneumatic low-inertia head GT 3M.

In welding of aluminum alloys, the electrodes of the machines must be periodically cleaned of contaminations. The number of spots between stripping is small (on the average near 50-70). For stripping of electrodes it is necessary to stop the welding process, to remove the article being welded from the zone between the electrodes and replace it once more. Multiple repetition of such operations results in the average-hourly productivity the welding process not exceeding 15-20 spots per minute (with the technical capabilities of modern machines - 35-40 welds per minute).

It is possible to increase the productivity of the machine by using multielectrode heads of the revolving type (Fig. 7). By turning head a quarter of a turn, the working electrode is instantly changed and welding of the extended seam goes on nonstop. After welding of an extended seam, all the electrodes can be cleaned by the usual methods. A mechanized device is being developed with a needlemilling cutter and suctioning off of the dust-like shaving for stripping the contaminated surface of the working pair of electrodes in process of welding the article. Creation of such a system will permit carrying out a continuous welding process and will almost double the average-hourly productivity of the machines, bringing it to its calculated rate.

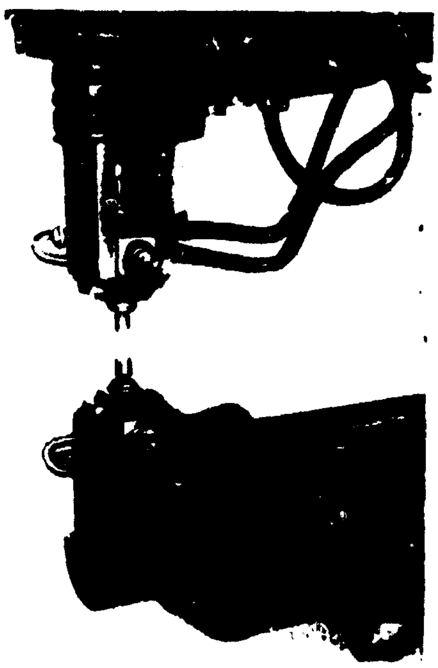


Fig. 7. Revolving four-electrode head for a welding machine.

The technology of manufacture of glue-welded structures also includes the process of applying the glue. With the capillary method of application, this operation is separated from the welding process and can be performed at specially equipped workstations. Depending upon the volume of production, the properties of the glue used, construction features, and other factors, the degree of mechanization of glue application can vary. In experimental works, with application of low viscosity glue there can be used the simplest guns - "pencils," the outflow of glue in which occurs under the impact of its own weight (Fig. 8). For more viscous glues pneumatic guns can be used, in which the glue is compressed by a piston connected with the plant pneumatic system through a precision air reduction valve to regulate excess pressure (Fig. 9).

Fig. 8. Hand gun for applying glue.

Fig. 9. Applying glue by means of a pneumatic gun.

A more improved design is the semiautomatic head equipped with a needle-shaped closing valve for covering the nozzle at the required moment, the roller guides which orient the nozzle with respect to the edge of overlap of welded joint (Fig. 10). Forward shift of head and speed control in applying the glue are performed manually. To apply the glue on rectilinear seams of great extent, the use of self-propelled automatic machines with electromechanical drive of shift along the seam is promising. One of the experimental models of an automatic machine is shown in Fig. 11.

Fig. 10. Applying glue, using a semiautomatic head.

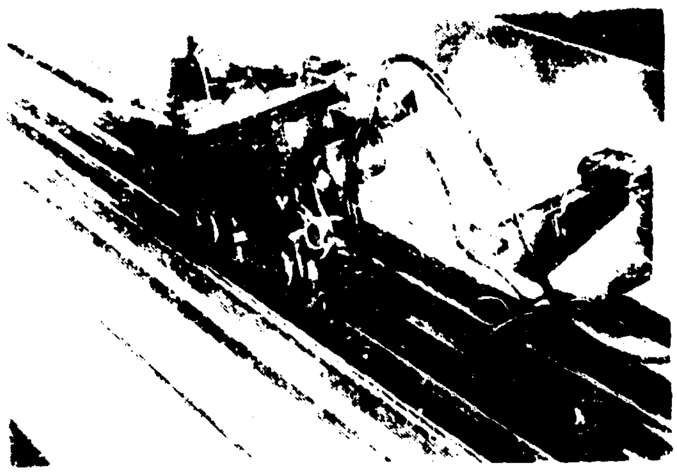


Fig. 11. Applying glue, using a self-propelled automatic machine.

The equipment of the workshop and the section preparing glue-welded structures by the use of the machines described and the means of mechanization permits making the process fully mechanized and economically expedient.

Electrodes. The quality of a welding of light alloys to a very great degree depends on correctness in the selection of material for the electrodes, the form of the working surface, and its preservation. In process of welding, heating and high pressure lead to deformation of working surfaces, mutual transfer of the metal welded being onto the surface of the electrode and copper onto the parts being welded. In contrast to welding of steels, in the

welding of aluminum alloys contamination of working surfaces of the electrodes essentially affects the quality of the joint. Here contamination of electrodes begins considerably earlier than their noticeable deformation, changing the area of electrode - part contact.

Depending upon various technological factors (first of all on the quality of preparation of the surface) electrodes are cleansed of contaminations after each 50-70 spots. The necessity for such frequent stripping serves as a considerable obstacle for mechanization and automation of the process of assembly of large dimension structures.

Electrode materials must be as heat- and electric-conducting as possible, be heat resistant and sufficiently hard. Pure copper, possessing high heat- and electrical-conductivity, is insufficiently durable and is heat-resistant and therefore is easily deformed.

Alloying of copper with additives of cadmium, chromium, and sometimes silver, permits the production of alloys useful for industrial manufacture of electrodes of welding machines (Table 47).

Alloy Mts5B is strengthened by hardening with subsequent artificial aging in the process of tampering, ensuring high hot hardness with sufficient electrical conductivity.

Chrome alloy Br.Kh07 is also an age-hardenable alloy, hardenable by heat treatment. Cadmium copper MK and copper M1, used chiefly for welding of soft aluminum alloys, are strengthened by cold deformation.

During spot welding of light alloys electrodes are used with a dome-shaped working surface. The radius of the dome of the electrode working surface is in functional dependence on the thickness of the part being welded (Table 48).

Table 47. Composition and basic properties of alloys for electrodes.

Alloy	Chemical composition in %	Electrical conductivity in % of electrical conductivity of copper	Temperature of softening in °C	Forging temperature range in °C	Heat treatment				HB hardness after heat treatment
					Hardening		Tempering		
					Temperature in °C	Holding in h	Temperature in °C	Holding in h	
Copper, cold-deformed M1	99,9 Cu	100	150—200	—	—	—	—	—	70—80
Cadmium copper KM	0,9—1,2 Cd; the remainder Cu	80—85	250—300	780—700	760—780	2—3	—	—	100-120 (cold hardening 50—70%)
Chrome cadmium alloy Kts5B	0,2—0,4 Cr; 0,2—0,35 Cd; the remainder Cu	80—85	380—500	900—700	940—960	0,5—1	470—490	4	110-125 (cold hardening 20-30%)
Chrome bronze Br.Kh07	0,4—1 Cr; the remainder Cu	70—80	350—450	800—700	980—1000	1—1,5	400—480	5	110—130

Table 48. Recommended dimensions of electrodes in mm.

Thickness of part	Radius of sphere of electrode	Minimum diameter of electrode	Thickness of part	Radius of sphere of electrode	Minimum diameter of electrode
0,5	50	12	2,5	150	25
0,8	75	16	3	150	30
1	75	16	4	150	30
1,5	100	20	5	200	40
2	100	25	6—7	250	50

For tansmission of large welding currents and forces of compression, and also to ensure airtightness and rapid replacement of electrodes, in most cases, bracing of electrodes in electrode-holders of welding machines by means of cone fit is used. During axial load and forces lower than 1500 kgf conicity of 1:10 is recommended, with great forces, to avoid jamming - a conicity of 1:5, with eccentric application of load (on irregularly-shaped electrodes) length of shank is increased and conicity equals 1:10.

The electrodes are removed from the recess of the electrode-holder by turning the shank or by ejection.

The simplest and most widely used is the first method, although in rotating shank with an extractor on the cone surface there can be formed burrs, impairing the airtightness and the electrical contact. The surface of the electrode being pressed by the extractor is also rather rapidly destroyed. A considerably longer service-life of the electrode is ensured by ejecting it from the recess by threaded attachments of various designs [6].

The electrodes are usually replaced after welding 50,000-100,000 spots. For welding of light alloys, only internal cooling of electrodes is used. On the life of an electrode a considerable influence is rendered by the distance between the working surface of electrode and end of the cooling duct which varies within limits of 12-17 mm.

Grinding of the surface should be performed on lathes with the use of special equipment or on special grinding machines with planetary mushroom milling cutter (Fig. 12). Grinding of the working surface of electrodes manually with files is impermissible.

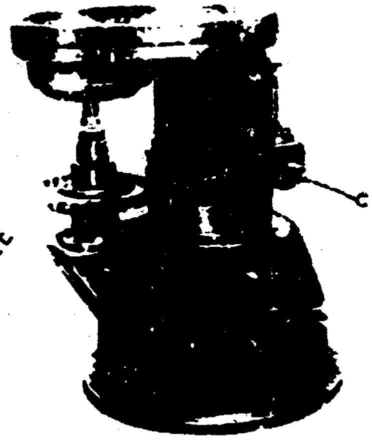


Fig. 12. Table machine-tool SHZ 1 for mechanized grinding of electrodes.

The spare electrodes in the working areas must be stored in a wooden container with individual cells for each electrode. The form of the working surface of the electrodes in the process of welding is periodically checked by special guages. In case of deviation of the indicated form from optimum, the electrodes must be removed and sent for regrinding.

Contamination forming on the working surface in the process of welding is removed by stripping with emery cloth, abrasive rubber, or wire needle-milling cutters with a mechanical drive.

The most widely-used method of stripping the surface is by emery cloth wrapped around a rubber pad and pressed between the electrodes. To ensure small force the distance between electrodes is set at 4-5 mm less than the thickness of the rubber plate. There have been developed a large number of designs for mechanized stripping [6], however the majority of them have obtained limited industrial application.

CHAPTER III

PRODUCTION TECHNIQUES OF GLUED SPOT-WELDED JOINTS

General Information

Production techniques of glue-welded constructions and the quality of glue-welded joints are largely determined by the properties of the glue compositions used for this and the distinctive features of their use. The great variety of operational and design features of modern machine-building articles imposes ever more stringent requirements on the properties of the glues used.

There are two known basic technological variants [10] in the manufacture of glue-welded joints: 1) spot welding with a layer of liquid glue preliminarily applied to the mating surfaces of the parts; 2) usual spot welding with subsequent introduction of glue by capillary method into the clearance between the elements being welded. Depending upon the properties of the glue composition, and also on the structural-technological features of the article being made it is possible to use the first or the second of these variants.

Welding over a layer of glue appeared as the first variant of industrial manufacture of glue-welded constructions analogous to welding over a layer of priming. This method does not put limitations on width of the lap and several other design parameters of the article, but presents rather high requirements on the physical chemistry properties of the glue.

The technological process of manufacturing of glue-welded joints according to the first variant can be divided conditionally into the following basic operations: 1) preparation of the glue; 2) preparation of the mating surfaces of the parts; 3) application of the glue to the mating surfaces of the parts; 4) assembling the elements of construction for welding; 5) spot welding with liquid glue; 6) polymerization (hardening) of the glue in the glue-welded joints.

As experience shows, for execution of glue-welded joints according to the first technological variant the majority of the liquid-fluid glues are useful (for gluing of metals), capable of being squeezed under pressure of electrodes of the welding machine from the contact sites, in order not to prevent the process of welding, and also to form a solid nonporous glue film. Furthermore, they must possess high viability, allowing welding of the article to be performed during 1-2 days after application of the glue layer. An exception are the rubber glues. Although they are pressed well from the contact sites, however, on their surface a dielectric film is created which prevents the normal flow of welding current and causes burns.

Rubber glues can be used for production of glue-welded joints only in the form of films. For welding with film glue it is necessary preliminarily to cut holes in the glue film and to combine them with the places for setting the welded spots on the article. The prepared film is applied to the mating surfaces of the lap of the parts, which are then put together, welded and polymerized. The welding is conducted on patterns. This method of welding is very laborious and can be used only in isolated special cases.

Duration of welding with a layer of finally prepared liquid glue depends on the initial viscosity of the glue, the thickness of the structural elements being joined, the temperature of the working site, force of compression of the electrodes of the welding machine and its work cycle.

The initial viscosity of many glues increases especially strongly with an increase in the content of filler, which leads to a lowering of the ability of the glue to be squeezed from the contact site. Unpressed glue in process of welding burns, and in so doing gases are abundantly separated, forming pores and air holes in the glue layer. This leads to a lowering of strength and disturbance of the airtightness of the glue-welded joint. An increase in the quantity of filler promotes lowering of shrinkage stresses in the glue layer and reduction in the prices of the glue composition. In order for the glues to be well pressed from the contact site in the process of welding, they must have a viscosity of not more than 0.12 s according to the cone viscosimeter. However, too high fluidity of glue leads to its emanating from the clearances of the joint, especially if the plane of overlap is inclined to the horizontal. As a result of this there appears unglued spots, airtightness of the joint is disturbed and its strength is reduced.

Accumulated experience permits recommending the use of welding conditions with variable electrode compression force (see conditions No. 8, Table 40). In so doing, the increased force of preliminary pressing facilitates a more complete squeezing of glue from the contact site and stabilization of properties of the glue-welded joint. However, preliminary pressing is not strictly obligatory. When using more liquid glues based on synthetic resins preliminary pressing is not required, and with such glue it is possible to weld qualitatively under the usual cycles of pressure (certainly, within limits of the viability period of the glue).

Conditions of welding with a layer of glue requires a decrease of welding current by 10-20% and an increase in the force of compression of electrodes by 15-25% (depending upon the glue used).

The quality of welding with a layer of liquid glue essentially depends on the pulse width of the welding current. With an increase in the rigidity of this pulse (i.e., with a decrease in its duration),

the process of welding with glue in a number of cases is hampered. With a rigid pulse of welding current and its rapid build-up, the welding contact does not succeed in becoming stabilized, glue is not completely pressed from the zone of contact, which leads to overheating (sometimes overburning of the metal) and also to formation of internal spattering. Furthermore, remainders of unpressed glue partially burn, and partially get into the molten metal of nucleus of the spot, contaminating it.

With a slowly growing pulse of welding current, pressing of the glue from the contact site occurs more fully by means of sufficient preheating and lowering of the viscosity of the thickening glue. At the moment of growth of current to a value ensuring formation of a molten nucleus, contact between the parts is stabilized.

Welding with a layer of glue must be performed in a location with a temperature not lower than 15°C and relative atmospheric humidity not lower than 75%. These parameters must be controlled by a thermometer and psychrometer set in direct proximity to the workstations for applying the glue. With a decrease in the thickness of parts being welded and the maximum permissible time from moment of preparation of glue to welding is reduced.

Various methods were studied for applying different glues to the mating surfaces: spatula, rigid brush, gun with a round and a slot nozzle. The simplest and most technologic turns out to be method of applying the glue with a gun with round nozzle in the form of roller along the axis of the welded spots. Diameter of the nozzle is selected experimentally (3-6 mm), depending upon width of the lap and thickness of the combinable parts. With the combination of the conjugate elements, the roller should completely fill the clearance in the overlap. It is permissible to press surpluses of glue along the edges of the overlap in the form of rollers with a width of not more than 2-3 mm (to the side).

Experience has shown that the variant of welding with a layer of liquid glue is insufficiently technological and convenient, since the presence of the glue layer on the mating surfaces of the parts (especially during welding at the end of the viability of the glue) not infrequently hampers the formation of the nucleus of the welded spot, frequently leads to formation in it of internal defects, hampers assembly and fixation of elements of the structure for welding. In connection with the difficulty of obtaining a uniform thickness of glue layer and irregularity of the clearances between mating parts, frequently the surpluses of glue pressed from under the overlap in the form of leaks get onto the surface of the parts and the electrodes, which causes overheating of the welding zone and burns. Here frequent stripping of electrodes is necessary, as a result of which productivity of the process decreases. This variant of welding should be used only in those cases when introduction of glue after welding is impossible due to its poor penetrating ability and short life, or when application of the second variant is irrational in connection with design features of the subassembly being welded (welding of edgings, cover plates, reinforcing bands, hoods, housings, etc.).

It is recommended that the process of manufacturing glue-welded joints according to the second technological variant be carried out in the following sequence; 1) preparation of mating surfaces for welding and gluing; 2) assembly of structural elements for welding; 3) welding of structural elements; 4) preparation of the glue; 5) introduction of glue by capillary method into the cavity of the welded joint; 6) polymerization of the glue in the glue-welded joints of the structural element.

For execution of glue-welded joints in accordance with the second technological variant glues are useful which possess the ability to fill clearances, and which have good penetrating properties (i.e., have good fluidity and sufficient viability), and are also able to form during hardening a solid dense (nonporous) glue layer.

Glue compositions with solvent possess the best penetrating properties and ability to fill clearances, but they have considerable shrinkage in the process of hardening and have reduced water-resistance. The degree of penetration of glue into the clearance of the joint and the reliability of filling the cavity of the overlap with it, are very strongly affected by the character of the degreasing of the mating surfaces; the presence of a fatty layer on them leads to nonwettability of the surface by the glue.

In case of introduction of glue into the cavity of the joint after welding, its penetration into the clearance of the overlap is conditioned by forces of capillary pressure. It is known that under the condition of wetting the surface of a solid by liquid the latter possesses properties of penetration into narrow, capillary spaces. In connection with the fact that solutions of synthetic resins in organic solvents (glues) are a moistening liquid with respect to the degreased surface of metal, there appears the possibility of using the force of capillary pressure to introduce the glue into the clearances of the welded joints carried out in the form of lap joints.

For case of a liquid found in the clearance between parallel plates located at distance d from each other, the force of capillary pressure is determined by the formula

$$P = \frac{\alpha}{R},$$

where α – coefficient of surface tension; R – radius of the concave surface of the meniscus of the layer of liquid.

With contact angle θ

$$R = \frac{\frac{d}{2}}{\cos\theta}$$

and

$$P = \frac{2\alpha\cos\theta}{d}.$$

Organic liquids usually moisten the surface of metals, therefore contact angle θ can be taken as equal to 0°; then

$$P = \frac{2\alpha}{d}.$$

It follows from this that the forces of capillary pressure act the more strongly the larger the coefficient of surface tension of the glue and the less the clearance between the welded sheets. In reality, regularity of penetration of glue into the clearance, obviously, is considerably more complex than as described above in connection with the fact that viscosity of glues considerably exceeds the viscosity of organic liquids.

The second variant of the process of manufacture of glue-welded constructions is the most technological, since the processes of welding and gluing can be divided, and then separately mechanized. Furthermore, the glue-welded joints thus produced processess higher strength indices, especially under cyclical loads, as compared to joints carried out by the method of welding with glue (see Chapter IV).

Recently abroad there has also been intensively conducted an investigation in the region of development and improvement in the technology of producing glue-welded joints and a study of their properties. The majority of foreign researchers [29, 30, 36, 37] in their description of glue-welded spot joints refer to the works of Soviet researchers. Foreign works differ from domestic basically in the character of materials used (alloys, glues) which is caused by the essential difference between the structure of the machine-building industry in the USSR and abroad. Thus, abroad investigations are conducted chiefly in the region of welding general purpose steels: in the USSR glue welded joints are used basically in constructions made from aluminum alloys.

Abroad, the widest investigations into the technology of manufacture and properties of glue-welded joints are being conducted

in the institutes, Technische Hochschule-Aachen and Technische Hochschule-Hannover (FRG) and the Central Institute of Welding in Halle (German Democratic Republic). The majority of published materials are of survey character and frequently are illustrated with experimental data from Soviet researchers [29, 36, 37].

Describing the two basic methods of introduction of glue into the welding zone of a joint (welding with glue and the capillary method of applying glue after welding), all foreign sources recognize the priority of the Soviet Union in the region of development and industrial use of the capillary method, indicating its considerable industrial advantages.

In experimental foreign works, the following were used as gluing materials: epilox EGK 19, epilox EKS 11, polycoll B, liozian LM, ZiS 217, mokodur, and certain other glues, chiefly self-setting.

Glue, epilox EGK 19 is a liquid resin on an epoxy base. Before application, a liquid hardener epilox 5 is added in a ratio of 100 parts of resin and 9 parts of hardener. The composition is suitable for use in approximately 30 minutes. Low viscosity makes it possible to apply this glue with a brush. Hardening occurs at room temperature, however it is recommended that the joint be heated, which reduces hardening time and increases the physical and mechanical properties of the glue. Good results are obtained with heating by infrared radiators at 80°C for 3 h.

Epilox EKS 11 - a glue on a base of epoxy resin of thick consistency, containing graphite as a filler. The hardener is epilox 5. The ratio of mixture during preparation of the glue: 100 parts of resin and 4.5 parts of hardener. Its viability is nearly 1 h. Time and temperature of hardening are the same as for glue, EGK 19. The glue is applied with a spatula.

Polycoll B consists of an unsaturated polyether resin G-Buna with a hardener. It is applied with a spatula and hardens at room

temperature in 30 minutes. For use in glue-welded joints, this glue was modified in the Central Institute of Welding of the German Democratic Republic, and obtained the name ZIS 217.

Experiments in the use of glues in glue-welded joints were directed towards investigating the effect of different fillers on the technology of welding and a study of strength properties of the joints. Welding with a glue layer was investigated since the viscosity of the glues used exceeded that permissible for the capillary method; furthermore, the width of overlap and constructive forms of the parts hampered the possibility of applying the glue after welding. The majority of the glues described can be used successfully for glue-welded joints of steel ST-34 with thicknesses of 0.8-3 mm using series welding machines.

The best technological properties are possessed by glues epilox EGK 19 and epilox EKS 11. As a filler, the glue mokodur with quartz powder is practically unsuitable. Quartz powder negatively affects the quality of the welded spot during its use also in other glues investigated. It is extraordinarily refractory, possesses electroinsulating properties, promotes the formation of coarse slag inclusions in the nucleus of the welded spot and decreases the strength indices.

The assumptions expressed by certain authors about the favorable effect on the welding process produced by glue containing a metallic or graphite filler in the majority of investigations were not confirmed. It was established only that these fillers do not prevent the welding process and do not cause a change in the conditions of welding as compared to welding with a layer of glue without filler.

All the foreign authors emphasize the considerable increase in strength of glue-welded joints as compared to welded, especially under live loads, which agrees with the results of Soviet researchers.

All foreign sources specially emphasize the economy of glue-welded constructions which do not require the manufacture of any special equipment other than series welding machines and complex attachments for applying the glue. The cost of the glue and its labor-input in applying it is undoubtedly offset by the sharp increase in the strength and operational reliability of the glue-welded constructions.

Survey materials (basically according to Soviet sources) are encountered also in the technical literature of Czechoslovakia [17]. The technical economic indices of glue-welded joints are highly regarded by Czechoslovakian scientists: there are put forth recommendations for their wide industrial use.

In Poland, in the manufacture of glue-welded constructions Soviet technical specification and records are used. Polish researchers are conducting, furthermore, original work on application of a new epoxy glue, ME 1, there has been developed a method of welding with film glue without preliminary breaching of holes in the film in the places of setting the welded spots. Welding is produced on low-frequency machines of the type MTPT 400 and the Seiakj with two pulses. The first pulse, of comparatively long duration (with little welding current), serves for preheating and softening of the film of glue; then at increased pressure the basic current pulse is supplied forming the welded spot [38]. This method presents an interest, however, judging by the given data, needs further improvement, since the instability of dimensions and strength of the welded spots, in our opinion, does not furnish a basis for its industrial application.

In the Central Institute of welding of the German Democratic Republic interesting experimental work was performed on investigation of the possibility of using glues during arc spot welding in a medium of carbon dioxide [29]. The experiments were conducted on samples of Steel St. 34. Welding was conducted with a consumable electrode in a medium of carbon dioxide.

Macroinvestigations of the welded seam showed that the zone of thermal influence is very great and the glue completely burns around the periphery of the welded joint, forming coarse slag inclusions on the border of the molten zone. The carburization of molten metal in the fusion zone is noticeable. Diverse variants of conditions did not give positive results, and the authors reached a conclusion concerning the unacceptableness of this form of welding for the production of glue-welded joints. In our opinion, such categorical conclusions are insufficient since in this case the capillary method of applying glue after welding can be used successfully.

In the Central Institute of Welding of the German Democratic Republic a method has been developed to increase the strength of welded seams by means of a surface applied glue layer (see Chapter IV).

Manufacture of Joints Using General Purpose Glues

Manufacture of joints using glue FL 4S. The conducted investigations, and also industrial experiments showed that glue-welded joints with the use of glue FL 4S can be successfully performed according to both technological variants. This is caused by the fact that the glue is well squeezed from contact sites under the pressure of the electrodes of the welding machine, without hindering the welding process, and at the same time fills clearances well and has considerable viability (not less than 8 h).

Possibility of welding with a layer of glue FL 4S was studied on different samples of alloy D16T with a thickness of 0.6-2 mm and on experimental panels 600·1000 mm (pack 1.5 + 1.5; 1.5 + 2 mm), consisting of sheathing and reinforcing ribs. Samples and panel were welded on machines with direct current pulse of the MTIP 450 and MTPT 600 type with the use of preliminary pressing and without it, and on machines of a variation of the MTP 200 type.

Liquid glue FL 4S is equally well applied to the mating surfaces with a brush with length of nap of 10-15 mm or by spatula. When welding materials of small thicknesses (up to 1.2 mm) the glue can be applied to one of the mating surfaces. In the manufacture of glue-welded frame constructions it is more expedient to apply the glue to the surface of the flange of the rigid section. Expenditure of this glue in glue-welded joints on the average equals 200-300 g/cm^2.

Inasmuch as glue FL 4S contains a solvent, then after application to the surfaces being welded prior to coupling the latter it is necessary to hold it for a short time in air for evaporation of the solvent. However, rather prolonged open holding strongly reduces the viability of the glue. Thus, after open holding for 2 h welding with the glue is very difficult. Covered holding increases the viability of the glue to 8 h, moreover in the clearance between sheets without access of air, the glue layer preserves initial viscosity for a long time and allows stable formation of the nucleus of the welded spot during 8-10 h from the moment of coupling of the parts.

It is not necessary to use preliminary pressing, if the welding with glue FL 4S occurs in the first half of its period of viability. If welding with the glue is conducted in the second half of its viability period and especially at the end of viability, then application of preliminary pressing is obligatory. In so doing, it is desirable that the force of pressing exceed the welding force by 2-2.5 times. In spite of the use of preliminary pressing, there is observed not quite complete pressing of glue from the contact sites. However, the very thin glue film appearing in the welding contact does not prevent flow of the welding current. A certain growth of contact resistance connected with incomplete pressing of the glue requires correction of welding conditions as compared to welding without glue. Usually it is sufficient to decrease the welding current by 8-10% and to increase welding force of compression of electrodes by 20-25%.

Experiments showed that the method of preparation of the mating surfaces does not render an essential effect on the character of the course of the welding process with glue FL 4S and on the strength characteristics of the glue-welded joints, but strongly affects the adhesional ability of the glue to the surface of metal in anodizing process. For the purpose of a detailed study of this question, the mating surface of flat samples and panels of alloy D16T were pretreated: 1) by chemical etching and then degreased; 2) by chemical etching and then additional cleaning with a wire brush or emery paper. After that, on the treated surfaces of the samples and panels a layer of glue was applied and then they were welded; further, the glue was polymerized and samples and panels were anodized under industrial conditions (by placing in hot water).

As a result of investigation of the samples and uncovered panels the following was revealed. Glue had insufficient adhesion to surfaces of samples which were not stripped after chemical etching and was easily peeled from it, and conversely, it has very high adhesion to the surface of samples which, after chemical etching, was additionally stripped by a mechanical method to an appearance of roughness; in this case the glue did not yield at all to removal even with help of considerable mechanical forces.

On panels with unstripped surface, the glue had good adhesion only to the surface of pressed section with natural roughness and in disassembling of the panels completely remained on the flange of the section being peeled from the sheet material (sheathing). There was local peeling of glue along the edge of the lap and, as a result, an insignificant flow of electrolyte in the formed clearance. On panels with a stripped surface, adhesion of glue inside the overlap was very high and uniform both to the profile and also to the sheet material. There was a complete absence of peeling of the edge of the glue layer and therefore there was no flow of electrolyte in the lap cavity.

Thus, it is possible to recommend the introduction into the technology of manufacturing of glue-welded joints with application of glue FL 4S the operation of obligatory stripping of surfaces to be welded by using a revolving metallic brush. Peripheral speed of the brush during stripping of the surface of plated aluminum alloys should average 10 m/s. With high speed and strong pressure of the brush on the metal it is possible to form clearances and disturbance in the continuity of stripping. Surfaces stripped with a brush should of necessity be degreased by acetone or ethylacetate. In the case of manufacturing glue-welded frame constructions one should produce stripping of the surface of sheathing according to a pattern in width exceeding the width of shelf of profile of rigidity by 6-7 mm.

The possibility of applying glue FL 4S after welding was tested on different samples and panels made from alloys D16T and AM6 with a thickness of 0.8 + 0.8; 1.2 + 1.2; and 2 + 2 mm, welded on an MTIP 450-2 with a single and multirow seam with various widths of lap. Mono and bilateral introduction of glue into the cavity of the joint was made with the help of a pencil gun. In so doing, there was observed good and uniform outflow of glue from the nozzle of the tool.

Glue FL 4S possesses high penetrating ability and exceeds all other glues in this respect. Thus, with one-sided introduction into the clearance of a two-row joint 1.2 + 1.2 mm thick it penetrates to a depth of 120-130 mm, and with bilateral – to a depth of 150 mm and more, thereby ensuring reliable filling of the whole lap cavity. In the course of the experiments, the glue was applied along the perimeter of the lap directly after welding of samples, and also after 24 and 72 h after welding. Appraisal of glue penetration was produced visually after drilling of the welded spots and subsequent destruction of the samples and panels.

With bilateral introduction of glue into the clearance of a multiple joint (pack 1.2 + 1.2 mm) with checkerboard location of

welded spots it penetrates to a depth of 100 mm, reliably filling the whole cavity of the lap, which testifies to its good ability to fill clearances. Introduction into the glue of a filler – aluminum powder PAK 4 in a quantity of 10% of weight of dry residue noticeably increases the density of the glue layer without worsening the penetrating ability of glue, but somewhat lowering the strength of glue-welded joint. These data further served as a basis for introduction of a filler in the composition of glue FL 4S.

Inasmuch as the process of glue penetration in clearances of great extent has still been insufficiently studied, a technology of applying glue after welding can be recommended at present for manufacture in basic frame glue-welded structures, consisting of sheet sheathing and long narrow (width up to 50 mm) reinforcing elements.

Establishment of optimum conditions of polymerization of glue FL 4S in glue-welded joints. The specific character of formation of glue-welded joints requires application of other conditions of polymerization of glue FL 4S as compared to the conditions used during regular gluing. The most rational is a step graph of conditions for hardening of glue in glue-welded joints.

Initially, on the basis of data of regular gluing there was experimentally selected the following step conditions of polymerization of glue, ensuring sufficiently complete hardening of the glue layer in glue-welded joints: raising the temperature to 80°C in 1 h 30 min and holding for 1 h, and then a raise in temperature to 140°C in 1 h 30 min and holding for 1 h, then cooling in air to room temperature. Application of these conditions under laboratory and then industrial conditions revealed the formation, in a number of cases, of bubbles and air holes in the process of hardening, disturbing the airtightness of the glue layer in a glue-welded joint. Furthermore, the necessity of holding at a temperature of 140°C for 3 h limited the field of application of glue-welded joints since in so doing, the possibility of using nonplated alloy

D16 and plated alloy with a thickness of less than 0.8 mm was excluded because of the possibility of development of intercrystalline corrosion.

A study of the kinetics of process of polymerization of the base of glue composition FL 4S permitted developing new, improved step conditions for its hardening. In Fig. 13 there is represented the graphic dependence of deformation furyl-phenolformaldehyde resin on the temperature in process of hardening obtained on the basis of experiments, conducted in conjunction with NIIPM. This graph permits tracing the change of physical properties of glue material in the process of polymerization. It is known that furyl-phenolformaldehyde resins belong to thermosetting materials, i.e., they irreversibly pass into another physical state during hardening. The curve in Fig. 13 is constructed for a solid (at room temperature) resin. From the graph it is clear that a gradual increase of temperature on section ab from 20 to 80°C leads to transition of the resin to a viscous-fluid state (the sharp rise of the curve). In this period, the resin is still in reversible state; furthermore, it is able to seal the pores and channels appearing during evaporation of the solvent, all the time forming a dense surface layer. On the section of curve bc there occurs a transition of the resin to an irreversible solid state: viscosity of resin here is sharply increased, furthermore, the ability to seal the channels forming in process of removal of solvent from it sharply decreases, and in a range of temperatures of 100-130°C pores can remain open. The section of curve cd characterizes the irreversible stable solid state of the resin.

The analysis conducted indicates a way of rational selection of conditions of polymerization of glue based on a given resin. It is obvious that it is necessary to stretch section ab in time with the purpose of removing as fully as possible the solvent from the glue composition. Gradual transition on section bc to an irreversibly solid state indicates the possibility of reducing holding at a temperature of termination of hardening (140°C) by means of more prolonged holding at intermediate temperatures (110-120°C).

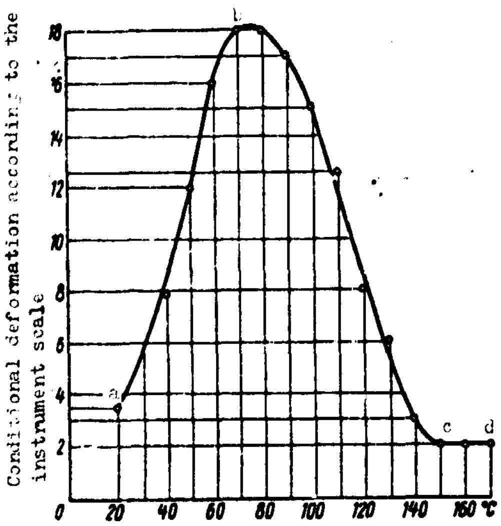


Fig. 13. Thermomechanical curve, showing dependence of deformation of furyl-phenolformaldehyde resin on temperature in process of hardening.

On the basis of the studied characteristics of change in state of the glue base - combined furyl resin in process of hardening it there are recommended the following most rational conditions of polymerization of the FL 4S glue layer in glue-welded joints of a naturally aged alloy D16T: raising the temperature to 80°C in 2 h after loading the articles in furnace and holding them for 1 h; raising the temperature to 120°C in 30 min and holding for 2.5 h, raising the temperature to 140°C in 30 min and holding for 30 min; then cooling in air. Testing of step conditions of heat treatment of glue under laboratory and industrial conditions showed that it ensures sufficiently complete removal of the solvent from the glue layer and hardening of it without formation of bubbles, air holes, and shrinkage porosity. Thanks to this, the glue-welded joints obtain high airtightness.

As a result of reducing to 30 min the time of holding articles at a temperature of 140°C, the development of intercrystalline corrosion is prevented in alloy D16T and, consequently, there appears the possibility of using parts made from nonplated (and plated small thickness) alloy D16T in a naturally aged state. The proposed conditions of heat treatment have been introduced into production.

A disadvantage in the described conditions of hardening glue FL 4S - its considerable duration, creating definite inconveniences for production. Therefore, in the case of using in glue-welded constructions artificially aged alloy D16T or other aluminum alloys not inclined to development of intercrystalline corrosion in a defined range of temperatures there can be used a somewhat simplified cycle of heat treatment of the glue; raising the temperature to 80°C in 0.5 h and holding for 0.5 h; raising the temperature to 160°C in 1 h and holding for 1 h, then cooling to room temperature. Total duration of these conditions amounts to 3.5 h, which is half as long as the conditions recommended for naturally aged alloy D16T. These conditions also ensure complete hardening of the glue, and preliminary heating removes porosity of the glue fillet and thereby ensures airtightness of the glue-welded joints.

Testing the possibility of anodizing glue-welded joints. One of the essential merits of glue-welded joints is the fact that they permit, in case of necessity, anodizing subassemblies and structures of aluminum alloys after welding and hardening of the glue for the purpose of protecting them from corrosion. At present the most widely used is sulfuric acid anode oxidizing of aluminum alloys. Here the conditions of oxidizing sheet plated material and pressed nonplated profiles are different. However for glue-welded articles such conditions are impermissible, since in the construction it is impossible to avoid combination of plated material with nonplated.

The possibility of anodizing glue-welded articles is determined mainly by chemical stability of a given glue in electrolytes and its ability to ensure airtightness of the lap cavity. Penetration of electrolyte into this cavity is extremely dangerous, since it causes corrosion of metal inside it. The possibility of anodizing of articles with glue-welded joints, the chemical stability of glue FL 4S in electrolytes, and its adhesion to metal was investigated on glue-welded samples of a technological sample and panels made from alloy D16T with dimension of 400·800 m (packs 1.2 + 1.2; 1.5 + 1.5 mm), carried out by glue welding, and also on sample

billets made of alloy B95T with dimensions of 150·30·3 mm with a longitudinal groove milled on one side 100·18·2 mm. In the groove glue of different thickness was applied. After heat treatment of the glue according to step conditions, all the samples and the panel were anodized (under plant conditions) in sulfuric acid with filler of film in dichromate. One batch of the glue-welded samples (6 pieces), two glue-welded panels and some of the sample billets (4 pieces) were anodized a second time with preliminary removal of the anode film by etching in a 5% solution of sodium hydroxide at a temperature of 60°C for 2-3 minutes. Analysis of the glue-welded samples and panels uncovered after the tests showed a complete absence of flow of electrolyte inside the seam, traces of corrosion of metal, and peeling of the glue. In the process of carrying out the tests there was not revealed on a single sample any corrosion, loosening and embrittlement of glue fillet and layer. The FL 4S glue turned out to be stable in all media both during single, and also during repeated anodizing. After anodizing, the glue-welded subassemblies of articles in places of articulation must be especially thoroughly washed of solutions used in the process of preparation, anodized, and filling.

Considering labor-input and the complexity of process of anodizing glue-welded articles, in recent years there have been developed and introduced into production new effective methods of anticorrosive protection of the articles mentioned without anodizing with the application of varnish and paint coatings.

Testing joints for resistance to fuel. As practice has shown, in many articles intended for the storage and transportation of different fuel media (fuel tanks and others) it is expedient to use glue-welded joints. Therefore a test of the latter for fuel resistance presents a specific practical interest.

In respect to fuel resistance tests were made on glue-welded samples and experimental panels (200·150 mm) made from alloy D16T

(pack 2 + 2), carried out by welding with glue FL 4S and with the introduction of glue after welding. After welding and heat treatment, the glue, samples and panels were subjected to sulfuric acid anodizing, and then testing in T1 fuel according to the following conditions: boiling in fuel at a temperature of 120-135°C for 120 h, at 135-140°C for 0.5 h, and at 140-145°C for 0.5 h, and then cooling to room temperature. Total time spend by the samples and panels in T1 fuel amounted to 520 h. Simultaneously with this, one batch of samples (15 pieces) was boiled in TP fuel at a temperature of 130°C for 30 h.

Fuel resistance of glue-welded joints was evaluated by the change in color of the fuel, visual inspection of glue fillet and layer, and also by comparative tests of samples for static shear (Table 49). In all cases, after the tests the color of the fuel remained unchanged, destruction of the glue fillet and layer was not observed. From Table 49 it is clear that the strength of the glue-welded samples after testing was not changed. Test results obtained testify to the satisfactory fuel resistance of FL 4S glue.

Table 49. Static shear strength of glue-welded lapped* samples of D16% (2 + 2 mm) before and after tests for fuel resistance (glue FL 4S; fuel T1).

Prior to test for fuel resistance	$\frac{854\text{-}1025}{911}$
After test for fuel resistance	$\frac{838\text{-}978}{910}$

*Dimension of overlap 30·30 mm.

**Each batch consisted of 15 samples.

<u>Production of joints with the use of KS 609 glue</u>. The possibility of producing glue-welded joints with the use of KS-609 glue was studied according to both technological variants. In so doing, it was established that the most rational method of welding is by liquid glue.

Experiments conducted on samples of alloy DT16T with a thickness of 1-1.5 mm. Before welding, on both mating surfaces of samples there was applied with a spatula a layer of glue with a thickness 0.3-0.5 mm or on one of these surfaces - a layer 1 mm thick. After that, on samples of one batch the glue was subjected to open holding in air. Samples of the other batch immediately after application of glue were walled up, and the glue was subjected to covered holding. The surface of samples before application of glue was cleaned with a metal brush and then degreased. After open and covered holdings, the samples were welded (Table 50) on an MTIP 600-4 machine with application of force of preliminary pressing equal to the forging force and without it. The KS 609 glue applied to one or both surfaces during welding evenly fills the lap clearance and is partially pressed from under the lap forming a fillet up to 5 mm wide. In the process of hardening, the glue fillet is partially pulled under the joint lap. Thanks to absence of solvents in KS 609 glue, the glue layer is sufficiently dense and monolithic.

From Table 50 it is clear that successful welding with KS 609 glue is possible for 1 h from the moment of its application. Covered holding somewhat increases the viability of glue as compared to open holding. Best results are obtained in welding with application of preliminary force of pressure. During welding for 1.5-2 h after application of the glue along with frequent splashes, there appear insignificant slag inclusions in the peripheral part of the nucleus; further increase in holding leads to partial and then to complete nonfusion.

Forcing of conditions by current and pressure either causes splashes or does not ensure a diameter of spot nucleus within assigned limits. An attempt to increase the viability of KS 609 glue by means of its refreshment with solvent (for example, acetone) did not lead to positive results. Introduction of solvent into the composition of this glue leads to a disturbance of polymeric joints, impairment of adhesion and strength, and loss of airtightness of

the joint. In producing glue-welded joints from aluminum alloys with KS 609 glue there can be recommended any method of preparation of surfaces to be welded which is used for regular spot welding. With any method of preparation, before applying the glue it is necessary to rub the welding surfaces of parts with acetone and to dry them until it is completely evaporated (Table 51).

Table 50. Quality of welding of alloy D16T (1.5 + 1.5 mm) with a layer of KS 609 glue after various holdings.

Holding of glue	Duration of holding in h	Character of course of welding process
Open	0.5	Welding proceeds normally
	1	The same
	1.5	Splashes appear
	2	Systematic splashes; slag inclusions in nucleus of spot
	3	Welding is practically impossible
Covered	0.5	Welding proceeds normally
	1	The same
	1.5	"
	2	Splashes appear; welding is hampered
	3	Welding is practically impossible

Application of KS 609 glue after welding was tested on standard samples for shearing tests and on panels with dimensions of 200·300 mm welded with a multiple seam. In connection with the short viability, introduction of glue into the cavity of the lap of the welded joint is difficult. The glue in initial composition has considerable viscosity which does not permit introducing it with a hand pencil-gun. In the course of the experiments the glue was applied basically with a spatula on the edges of the lap joint and only in individual cases was a pneumatic gun used.

Table 51. Recommended conditions for spot welding with glue KS 609.

Alloy	Combination of thickness in mm	Radius of dome of electrodes in mm	Welding current in A	Force of compression of electrodes in kgf: During pressing	During welding	During forging	Duration of preliminary pressing in s	Duration of welding in s	Average diameter of nucleus in mm	Steps of transformer
Machines with direct current pulse										
AMg6	1+1	50/50	32 000	1000	400	1000	0,2	0,1	5	IV
	1,5+1,5	75/75	34 000	1500	600	1500	0,3	0,12	6,5	V
	2+2	100/100	36 000	2400	800	2400	0,3	0,14	7,5	VI
	2+1	100/50	32 000	2000	600	2000	0,2	0,1	5	V
AMtsAM	1,5+1,5	75/75	31 500	1500	500	1500	0,3	0,12	6,5	V
	2+2	100/100	35 000	2100	650	2100	0,3	0,14	7,5	V
	1+1	50/50	32 000	1000	250	1000	0,2	0,1	5	IV
Machines with alternating current										
AMg6	1+1	50/50	19 000	—	360	—	—	0,16	5	—
	1,5+1,5	75/75	21 000	—	480	—	—	0,24	6,5	—
	2+2	100/100	25 000	—	600	—	—	0,36	7	—
AMts	1+1	50/50	21 000	—	240	—	—	0,16	5	—
	1,5+1,5	75/75	25 000	—	300	—	—	9,24	6,5	—
	2+2	100/100	28 000	—	360	—	—	0,36	7	—

Glue KS 609 when applied after welding and during holding of the joint at an angle of 40-60° to horizontal for 3-4 h penetrates the clearance to a depth of 20-25 mm with a thickness of welded sheets of 1.5 + 1.5 mm and more. The thickness of sheets (i.e., clearance between them after welding) essentially affects the penetrating ability of the glue (Table 52).

Decreasing the quantity of filler to 25 parts by weight somewhat improves the condition of penetration of glue into the clearance of the joint and permits filling a lap with a width of 20-25 mm with thickness of sheets up to 1 + 1 mm.

Table 52. Depth of flow of glue KS 609 into the clearance of a joint depending upon thickness of sheets being welded.

Combination of thickness in mm	Duration of holding in h	Depth of flow of glue in mm according to position of sample in the process of holding	
		horizontal	at an angle of 30° to horizontal
3+3	1 3	20—25 20—25	20—25 25—30
2+2	1 3	18—20 20—25	20—25 25—30
1,2+1,2	1 3	3—5 15—20	15—20 20—25
0,8+0,8	1 3	Almost none In separate spots	In separate spots 8-10, local non-gluing

The reason for hampered flowing of glue KS 609 in comparison, for example, with glues FL 4S, VK 1, and others is mainly its short viability, leading to considerable increase in viscosity of the glue in the process of its application. For confirmation of this, KS 609 glue, in the composition of which was in all 10 parts by weight of filler and in which a solidifier was absent, was introduced into the lap clearance.

In this case, the initial viscosity of the glue was preserved for a prolonged time and its penetrating ability turned out to be very high, however gluing properties here sharply decreased (to τ_B = 3-5 kgf/cm^2).

Considering the thermoplastic properties of glue KS 609, attempts were undertaken to increase its penetrating ability by means of heating the glue or the metal on which it was applied to 60-80°C. In the process of investigation of diverse variants a certain increase of penetrating ability (with a thickness of samples of 2 + 2 mm) was observed only during application of the cold glue on a heated sample, however, average depth of flow of glue into the lap cavity remained practically on level with that shown in

Table 57. Preliminary heating of glue somewhat increased the density of the glue layer, completely removing the presence of air bubbles in the glue fillet. Heating of the joint with the glue applied did not increase the penetrating ability of KS 609 glue.

Thus, preheating the glue or metal does not essentially increase the penetrating ability of KS 609 glue, but noticeably complicates the technology of its application. Introduction of the glue into clearance of the joint after welding is successfully used only for elements with a width of overlap of not more than 20-25 mm with a thickness of welded sheets of 1.2 mm and more.

For joints with wider overlap, in a number of cases, it is possible to use bilateral introduction of glue into the lap cavity. Here inside the overlap formation of voids is possible, which, however, do not prevent the phosphate coating processing of the glue-welded subassemblies. The boundary fillet made from glue KS 609, when it is qualitatively produced, ensures reliable protection of the joint cavity against the entry of electrolyte in process of anodizing even when it is incompletely filled by glue. After drilling the welded spots and disassembling the anodized experimental samples, penetration of electrolyte into the lap cavity is not revealed either visually or with the help of chemical indicators.

In the process of industrial checking, actual glue-welded constructions carried out with application of glue KS 609 according to both technological variants turned out to be air tight after testing on special installation with a penumatic pressure of 1.5 at while holding at this pressure for 3 h. The simultaneous influence of excess pressure and impact loads (joints were punctured with an air hammer) also did not disturb the airtightness of the joints.

Manufacture of joints with the use of glue KLN 1. Glue-welded joints using glue KLN 1 can be prepared according to both technological variants. However, the most rational method of welding is by liquid glue.

The surface of samples and panels of alloy D16T 1-2 mm thick, before application of glue and before welding are cleaned with a metal brush or emery paper and then blown with compressed air and degreased with acetone or alcohol. The glue is applied with a stiff brush to both mating surfaces of samples in a layer up to 0.5 mm or to one of these surfaces in a layer up to 1 mm. Then the samples are welded on an MTIP 600-4 machine with direct current pulse with application of force of preliminary pressing and without it. In both cases, the glue during welding filled the clearances of overlap well and evenly and was cleanly pressed from under it, forming a fillet 3-5 mm in width. Thus glue, similar to glue FL 4S and VK 1 was easily pressed from the contact sites under the pressure of the electrodes of the welding machine and did not prevent the flow of welding current.

In all the cases mentioned under optimum conditions of welding there was observed a stable formation of the nucleus of welded spots of prescribed dimensions and form without splashing. In the nucleus of the spot there is not revealed slag and other inclusions. Inasmuch as KLN 1 glue practically does not contain a solvent (dry residue 99%), then during hardening does not give off gaseous components, and also causes almost no bubbling and shrinkage. This permits producing a glue-welded joint with a solid monolithic and nonporous glue seam, which guarantees their sufficient airtightness. Optimum conditions of welding with glue and without glue essentially differ from one another. Thus, force of compression of electrodes when welding with glue should be increased 10-14%, and welding current must be reduced 5-8%.

The process of welding with glue with application of preliminary pressing force proceeds more stably and steadily than without it. In this case, squeezing of the glue from the contact site is more complete. Preliminary compression force of the welded parts should last 0.4-0.6 s, and its value should be approximately equal to the forging force.

Results of welding with KLN 1 glue strongly depend on the duration of holding it (especially open) in air and on the temperature. In the case of covered holding, welding with a layer of glue can be successfully fulfilled in 2-2.5 h from the moment of its application at a temperature on location of not higher than 25°C.

The higher the temperature at the location, the more intensively the viscosity of KLN 1 glue grows and, consequently, the time is reduced during which qualitative welding is ensured. Within 3.5-4 h from the moment of application of the glue there will be formed partial nonfusions, and within 5 h - annular penetration and coarse slag inclusions in the nucleus of the spot, and also partial splashes.

Forcing the conditions by welding current and pressure causes systematic splashes and does not ensure production of a diameter of the nucleus of the spot within prescribed limits.

Inasmuch as glue composition KLN 1 does not contain solvent in its composition and hardens at room temperature, the glue layer before welding should not be given open holding. The latter sharply shortens the viability of the glue. Thus, during welding within 0.5 h after application and open holding of the glue in air there are already observed splashes and there appear insignificant slag inclusions in the peripheral zone of the nucleus of the spot.

In the manufacture of glue-welded frame constructions, glue KLN 1 is more rationally applied to one surface of the flange of the bracing section being welded to the sheathing. In all other cases it is recommended that the glue be applied to both mating surfaces of the parts to avoid the formation of local nongluing. In this respect, KLN 1 glue differs somewhat from other self setting glues (especially from glues of the EPTs [epoxy adhesive type]).

Glue KLN 1 is equally well applied both manually with the help of a spatula or brush and also by the method of pneumatic squeezing

from a gun. Expenditure of this glue in glue-welded joints averages 250-300 g/m^2. With increased viscosity of the glue its expenditure is increased.

The ability of KLN 1 glue to harden without heating makes it practically nontoxic, since in so doing no volatile substances are released. However, applying the glue on mating surfaces is successful only with intake-exhaust ventilation.

In manufacturing glue-welded joints from aluminum alloys with application of KLN 1 glue it is possible to use any of the methods for preparation of the surface of parts used for regular spot welding of these alloys. With any method of preparation, before applying the glue it is necessary to rub the mating surfaces of the parts with alcohol (application of acetone is undesirable), and then to dry them. Surfaces of parts cleaned by the mechanical method must be preliminarily blown with dry compressed air.

Application of KLN 1 glue after welding was tested on different samples and panels from alloys D16AT and AMg6, 0.8-2 mm thick. In connection with the short viability of glue, introduction of it into the lap cavity of the welded joint presents specific difficulties. The glue in its initial composition has considerable viscosity and therefore emanates comparatively slowly from a hand pencil-gun. For this purpose it is more rational to use a pneumatic gun ensuring a more intense supply of glue in the lap clearance.

During introduction of KLN 1 glue into the clearance of the welded joint the samples are disposed horizontally and at an angle of 40-50°C. When applying glue after welding and holding samples with a thickness of 1.5 + 1.5 mm in horizontal position for 2.5-3 h it penetrated the clearance to a depth of 20-25 mm, and with the same holding at an angle of 40-45° to horizontal — to a depth of 25-30 mm. With an increase in thickness of the welded sheets the penetrating ability of glue is somewhat increased, which is caused

by the increase in the lap cavity. With thickness of samples of 0.8 + 0.8 mm the flow of glue in this cavity is strongly retarded, in individual places certain gaps are observed.

Considerably best results are given with the method of consecutive bilateral introduction of glue into the lap cavity, which has been widely tested under industrial conditions by N. I. Lopatin. Here the glue initially flowed out from one side of the overlap and then, upon the expiration of 2-3 h was introduced from the opposite side. Analysis after drilling of uncovered welded spots of samples of a technological specimen 20-30 mm in width and 0.8-2 mm thick, and also panels 200·300 mm consisting of sheathing and corners welded showed in all cases the presence of a stable filling with glue of the entire lap cavity.

Thus, the use of KLN 1 glue with introduction of it into the joint clearance after welding should be limited basically to structural elements with 20-25 mm width of overlap with a thickness of welded sheets of 1 mm and more. For joints with wider overlap, in a number of cases bilateral introduction of glue into the lap cavity is possible.

In Tables 53 and 54 there are given comparative data (obtained by N. I. Lopatin) average strength of welded and glue-welded joints of alloy D16T carried out with the use of bilateral introduction of KLN 1 glue into the lap cavity and also analogous glue-welded joints with drilled spot. Upon completion of introduction of glue, the glue-welded samples were subjected to holding in air at room temperature for 10 days for full polymerization of the glue. On samples 1 mm thick welded spots were drilled by drill 6 mm in diameter and 1.5 and 2 mm thick – a drill by 8 mm in diameter. As can be seen from Table 53, introduction of KLN 1 glue into the cavity of the welded joint promotes an increase in its strength, where a considerable increase in strength is observed with smaller thickness of combinable sheets which will agree with the results

of the investigations described in [10]. The data given in Table 54 indicate that the glue seam in glue-welded joints carried out with KLN 1 glue possesses sufficiently high strength, comparable with analogous specification characteristics of this glue.

Table 53. Static shear strength of joints of alloy D16T; glue KLN 1 introduced after welding.

Combination of thicknesses in mm	Average diameter of nucleus of spot in mm	Extent of overlap in mm	Average breaking load on the spot (joint) in in kgf		Ratio of shear force glue-welded joint to shear force of welded joint
			Welded	Glue-welded	
1+1	5,2	20,1×19	261	510	1,95
1,5+1,5	6,7	20×20	523	610	1,17

Table 54. Shear strength – shift of glue seam in glue-welded joints (glue KLN 1) with drilled welded spot.

Combination of thicknesses in mm	Extent of overlap in mm	Diameter of hole in mm	Breaking load in kgf	Shear stress-shift in kgf/cm^2
1+1	21×17,8	6	466	146
	16,8×18,8	6	380	121
	21×10,7	6	596	153
1,5+1,5	20×20	8	450	146
	19,7×19,6	8	447	147
	19,8×20,6	8	472	160
	20,2×19,6	8	422	141
	20,2×19,8	8	540	170
2+2	21×19	8	512	160
	20×20,5	8	466	150
	20,3×20	8	424	138

Investigations conducted by the authors and also by N. I. Lopatin showed that KLN 1 glue layer in glue-welded joints in hardened state are sufficiently resistant to the action of oils, kerosene, gasoline, alcohol, and also the electrolytes utilized during oxidizing and anodizing. However its water resistance is insufficient.

During direct contact of the glue layer with sea and fresh water there occurs partial destruction of layer along the surface, which can negatively affect the strength and airtightness of the glue-welded joint.

Corrosion resistance of the glue seam and its ability to hermetically seal clearances of glue-welded joint from the flow of water and electrolytes during anodizing was determined by visual inspection after stay in mentioned media of uncovered glue-welded test piece of a technological specimen of alloy AMg6 and D16T, metallographic investigation of macrographs cut from these test pieces, and also according to the results of comparative mechanical shearing tests of glue-welded samples of alloy D16T (pack 1.5 + 1.5 mm) with a spot drilled with a drill 8 mm in diameter (Table 54). After introduction of glue into the cavity of the welded joint, the samples were held in air for 7-10 days for full polymerization of glue, and then loaded in appropriate media, where they were held 5-60 days. After opening of the welded seams, on the samples there were revealed no traces of corrosion, peeling of the glue and flow of electrolyte inside the seam. As can be seen from Table 55, strength of the glue-welded seam after the active effect on it of different media for 30 days and more decreases insignificantly.

Table 55. Shear strength τ_B in kgf/cm^2 of glue-welded samples with drilled spot after various holding in a given corrosionally-active medium (according to N. I. Lopatin).

Medium	Duration of tests, in days			
	5	15	30	60
Oil	125	116	120	120
Kerosene	135	120	120	110
Sea water	150	146	130	—
Fresh water	147	122	130	—
Electrolyte (oxidizing)	150	—	—	—
Electrolyte (anodizing)	149	—	—	—
Air (control samples)	150	120	120	130

In connection with the low water resistance of KLN 1 glue it is necessary to protect the ends of glue-welded joints with paint and varnish coatings.

For the purpose of checking the reliability of the hermetic sealing by KLN 1 glue of the cavity of welded joints and the efficiency of the glue layer, N. I. Lopatin subjected to comparative tests on a special installation, glue-welded and analogous riveted panels of alloy D16T under the impact of hydrostatic pressure and on static bending. The panels consisted of sheet sheathing 1.5 mm thick, strengthening ribs (corners, 20·15·1.5 mm), frames (made from sheet with a thickness of 1.5 mm and then heat treated). On one panel the strengthening ribs were welded to sheathing, and frames were riveted; on the other panel the strengthening ribs and frames were welded to sheathing.

Glue introduced into the cavity of the joint after double lap welding and then washed 7-10 days for its polymerization. For best flowing of the glue the panels were set at an angle of 40-45°. Strengthening ribs and frames were riveted to sheathing (in riveted and glue-welded panels with riveted frames) by hermetic U30MES5.

As a result of investigations, there had been established the following: 1) static bend strength of riveted and glue-welded panels is practically identical; 2) destruction of panels under the impact of hydrostatic pressure occurs, as a rule, along the frames; shearing and tearing out of rivets or welded spots along strengthening ribs was not observed; 3) glue-welded panels of both types have noticeably the best airtightness and less plastic deformation. Thus, disturbance of airtightness for riveted panels was observed even at a pressure of 0.2 kgf/cm^2 whereas for glue-welded – at 0.5-0.6 kgf/cm^2.

Glue-welded joints carried out with KLN 1 glue possess high thermal stability: after the effect of a temperature of 80°C for 1500 h their strength remains practically unchanged.

<u>Manufacture of joints with the use of glues EPTs 1, EPTs 2, EORTs and K 153</u>. The basic method of manufacturing glue-welded

joints with the use of glues EPTs 1, EPTs 2, EORTs, and K 153 is welding with liquid glue. Investigations were conducted on different samples of alloys AMg6M and AMgP with thickness of 1.5-2 mm. Test pieces were welded on an MTIP 600-4 machine with application of force of preliminary pressing equal to force of forging and without it.

Results of welding with a layer of EPTs glues depend strongly on filler content. The content of filler in a quantity of 150 parts by weight strongly hampers the process of welding with glue (Table 56), since here the viscosity of glue is sharply increased its ability to be pressed from contact sites decreases and duration of open holding is also reduced. On destroyed glue-welded test pieces of a technological specimen there is observed, as a rule, the presence of remainds of nonpressed glue from the contact sites and pores in the glue layer, insufficient quality in welded spots and intense splashing. In the nucleus of the spot there are revealed pores, caused, obviously, by combustion of remainds of nonpressed glue.

Table 56. Effect of quantity of filler in glue on process of welding with glue*.

Glue	Quantity of filler in parts by weight			
	150	100	75	50
EPTs	Splashing and burning of metal	Splashing and pores in molten nucleus	Splashing in 50% of the samples	High-quality welded spots
EORTs	Splashing and pores in the glue layer	Splashing in 25% of the test pieces	High-quality welded spots	The same

*Each batch consisted of six five spot-welded samples of alloy AMG6 (1.5 + 1.5 mm).

With a decrease in quantity of filler to 100-80 parts by weight the course of the process of welding with glue is improved noticeably

and application of glue is also facilitated. Best results were obtained with welding with a layer of EPTs glues containing filler in a quantity of 50-60 parts by weight. In this case glue fills the lap cavity well and evenly and is partially pressed from under it, form a filler 4-6 mm wide. It is easily pressed from the contact sites under the pressure of the electrodes of the welding machine and does not prevent the flow of welding current. There is observed stable and qualitative formation of nucleus of welded spots of prescribed dimensions and form without splashing.

In contrast to EPTs glues, the presence of increased filler content in EORTs, EOSTs and K 153 glue compositions considerably has less effect on the process of formation of the molten nucleus of the spot during welding with glue. Thus, for example, th process of welding with glue proceeds sufficiently stably, without splashing in the case of using glue compositions EOSTs 1 (with hydroxyterpene resin) and K 153, containing filler in a quantity of 90-100 parts by weight. The K 153 glue with a quantity filler identical with glue EPTs has the best fluidity and longer viability.

Introduction in composition of EOSTs 1 of up to 10 parts by weight of polyether MGF 3 (glue EOSTs 2) considerably improves its plastic and technological properties and makes the glue more useful for production of glue-welded joints. Optimum quantity of filler in glues EOSTs 2 and K 153 intended for production of glue-welded joints should be 80 parts by weight. Open holding of the applied glue is permissible up to 1 h.

Increasing the content of polyether in glue to 25 parts by weight increases the plastic properties of the glue layer without lowering the strength characteristics of the latter has a beneficial effect on the course of the welding process. The experiments conducted permit recommending for production of glue-welded joints, in contrast to gluing, the following optimum composition of glue EPTs: epoxy resin ED 5 or ED 6, 100 parts by weight; polyether MGF 3 or TGM 9,

25 parts by weight; distillation residues of hexamethylenediamine GMDA (solidifier) 25 parts by weight; cement (filler) 50 parts by weight. For EORTs glue (with hydroxyterpene solvent 40 parts by weight) and glue K 153, the quantity of filler can be brought to 80 parts by weight.

Tensile strength of the EPTs and EORTs glue layer of the mentioned composition is increased in time and attains maximum value corresponding to 136 and 130 kgf/cm^2 in 14 days after manufacture of the glue-welded joints. Inasmuch as the process of polymerization of these glues proceeds rather intensively, then even in 24 h the strength of the glue-welded joints attains 85-90% of maximum strength.

Glues EPTs and K 153 do not contain solvent, during hardening they do not release gaseous components and have hardly any bubbles and shrinkage. This makes it possible to obtain a glue-welded joint with a sufficiently dense and monolithic glue layer. The EPTs and K 153 glue layer is resistant to the action of media used during chrome- and sulfuric acid anodizing. The samples and panels welded with glue after hardening of the glue at a temperature of 20°C for 10 days underwent mono- and double anodizing in sulfuric acid with filling of film in dichromate. After these tests there was not revealed corrosion or loosening of glue fillet and layer. Flow of electrolyte inside the seam was also absent.

The stability in the course of the process of welding with EPTs and K 153 glue and the strength the glue-welded joints thus obtained depends strongly on duration of open and covered holding of the parts before welding. The glues mentioned, containing a solidifier rapidly acquire viscosity, especially during open holding, which quickly lowers their viability and accelerates the process of polymerization. The polyether found in the composition of the

glues interacts during open holding with oxygen of the air and lessens their viability more intensively.

Optimum permissible duration of open and covered holding, for example of EPTs glue, before spot welding was based on standard chemically stripped test pieces of alloy AMg6M with a thickness of 2 mm. On each sample an approximately equal quantity of glue was applied then they were welded with glue in batches through intervals of 20 min and tested for shear and shift. With more than 90 min duration of covered holding and more than 50 min open holding, the strength of the glue-welded joints drops sharply, the process of welding proceeds unstably and considerable splashing is observed. On destroyed test pieces of a technological specimen and macrographs here there are revealed unstable welded spots and defects in the form of pores and gas pockets in the glue layer.

Expenditure of glue depends on the degree of treatment of the surface, the viscosity of the glue composition, methods of application, thickness of the glue layer, and so forth. With a decrease in the thickness of the glue layer the strength of the glue joint is increased. Optimum thickness of glue layer in a glue-welded joint (0.1-0.25 mm) ensures the required strength of the joint. Superfluous expenditure of glue leads to an increase in the thickness of the glue layer and, consequently, to lowering the strength of the joint, contamination of the electrodes during pressing of glue from under the overlap, and also to an increase in the cost of production of glue-welded constructions.

Optimum expenditure of EPTs and EORTs glues and the method of applying them were determined on standard single spot-welded test pieces and multiple spot-welded plates with dimensions of 250·80 mm and a thickness of 1.5 mm. A measured quantity of glue was applied to the mating surfaces of the samples and then they were welded. Experiments showed (Table 57) that optimum expenditure of glues EPTs 1 and EPTs 2 is 600 g/cm^2, and glue EORTs 500 g/m^2.

With open holding up to 30 min, the expenditure of glues EPTs 1 and EPTs 2 can be reduced to 500 g/m^2. With an increase in open holding and growth of viscosity of glue, its expenditure is somewhat increased. However, one should consider that, in the process of welding, the glue is heated and becomes more liquid. Superfluous glue thus emanates from the seam, soiling the electrodes and the parts. For the purpose of establishing an optimum method of applying a self-setting (EPTs) for welding, on one and both mating surfaces of standard samples of alloy AMg6M, stripped by chemical means and a wire brush, there was applied by spatula an identical quantity of EPTs 1 glue then the samples were welded and tested for shear. Shear strength of glue-welded samples with mono- and bilateral application of glue is practically identical (Table 58). However, practice shows that liquid epoxy-cement glues are more rationally applied for welding on one of the mating surfaces in a layer 0.7-0.8 mm thick.

Table 57. Determination of expenditure of glues EPTs and EORTs for manufacturing glue-welded joints.

Glue	Expenditure of glue on 1 m^2 of surface in g				
	400	500	600	700	800
EPTs 1	Glue film is disturbed, nongluing	50% samples with high quality joint	High quality joint	With open holding up to 30 min, a high quality joint	Pressed glue soils electrodes
EPTs 2	The same	35% samples with high quality joint	The same	The same	The same
EORTs	Individual defects in the glue film; 60% high quality samples	High quality joint	The same	Pressed glue electrodes and parts	The same

Table 58. Shear strength τ_{cp} of glued-welded single spot samples of alloy AMg6M.

Method of application of glue	Combination of thickness, in mm	Number of samples in batch	Destroying forces in kgf	τ_{cp} in kgf/cm²
One-sided	1+1 1.5+1.5 2+2	10 8 6	528 840 1038	85 134 167
Bilateral	1+1 1.5+1.5 2+2	10 5 6	524 846 1030	84 135.8 165

International cooling before applying for welding of a prepared self-setting glue, containing epoxy resin noticeably increases its viability and, consequently, improves manufacturability. Thus, glue of epoxy-cement composition (with filler 50 parts by weight) 30 min after preparation was specially cooled with running water to a temperature of 10-12°C. As a result of this, it preserved initial viscosity for an additional 30 min, which permitted successful welding with the given glue for 1 h under initial conditions without any correction.

Preservation by glue additionally cooled, of stable viscosity during a prolonged time considerably facilitates and accelerates the process of applying it to the mating surfaces. This process can easily be mechanized by means of the simplest glue-feeding bunker attachments. If, however, EPTs glue is used without additional cooling, then application of it to the mating surfaces, especially in large dimension constructions, 30 min after preparation is possible only manually with help of a spatula. The EPTs glue prepared on a more viscous resins, for example ED 6, can be more rationally applied by the method of pressing from a gun [10].

In Tables 59 and 60, for example, there are given recommended conditions of spot welding of certain aluminum alloys with liquid EPTs glue on MTPT machines with direct current pulse. Surfaces of the samples for welding were subjected to chemical etching in a solution of orthophosphoric acid of standard composition with subsequent mechanical stripping with a wire brush.

Table 59. Recommended conditions for spot welding of aluminum alloys with glue EPTs on MTPT 400 machine with direct current pulse.

Alloy	Combination of thickness in mm	Radius of dome of electrodes on side of part		Force of compression of electrodes, in kgf			Duration of preliminary pressing in s	Welding current, in A	Pulse length of welding current, in s	Step of transformer
		Thick	Thin	During pressing	During welding	During forging				
AMg6	1+1	50	50	1000	400	1000	0,2	32 000	0,1	IV
AMg6	1,5+1,5	75	75	1500	600	1500	0,3	34 000	0,12	V
AMg6	2+2	100	100	2400	800	2400	0,3	36 000	0,14	VI
AMg6	2+1	100	50	2000	300	2000	0,2	32 000	0,1	V
AMtsAM	1+1	50	50	1000	250	1000	0,2	32 000	0,1	IV
AMtsAM	1,5+1,5	75	75	1500	500	1500	0,3	31 500	0,12	V
AMtsAM	2+2	100	100	2100	650	2100	0,3	35 000	0,14	V

Table 60. Recommended conditions of spot welding of aluminum alloys on MTPT 600 machines with direct current pulse.

Alloys being welded	Combination of thickness, in mm	Type of joint	Radius of dome of electrode, in mm	Force of compression of electrodes, in kg			Welding current, in A	Step of transformer
				Preliminary	During welding	During forging		
AMg6M + AMgM	2+1	Welded	50	500	500	1280	41 000	II
AMg6M + AMgM	2+1	Glue-welded (with liquid glue EPTs)	50	560	560	1450	39 000	I
AMg6M + AMgP	2+1	Welded	50	580	580	1350	41 000	II
AMg6M + AMgP	2+1	Glue-welded (with liquid glue EPTs)	50	650	650	1550	39 000	I
AMg6M + AMgP	2+1,5	Welded	75	680	680	1650	47 500	V
AMg6M + AMgP	2+1,5	Glue-welded (with liquid glue EPTs)	75	840	800	1900	45 000	IV

Note: 1. Lower electrode has flat contact surface. 2. The sheet of greater thickness is located on the side of the lower electrode. 3. Pulse length of welding current 0,1 s. 4. Forging force lag 0,06 s.

General recommendations for establishing conditions of welding with glue EPTs, in contrast to conditions of welding without glue, consist in the following: 1) duration of preliminary force of compression of parts being welded should be not less than 0.5 s; 2) preliminary pressing of parts is required with a thickness of the thinner part $\delta \geq 1.5$ mm; here preliminary force $P_{o6} \geq (2.3-2.5) \cdot P_{cB}$, where P_{cB} – force of compression of the parts by the electrodes during welding; 3) a certain growth of contact resistance connected with incomplete pressing out of the glue requires correcting the conditions of welding, in contrast to welding without glue. Force of compression of electrodes during welding and forging must be increased 12-18%; welding current should decrease 4-6%.

The conducted investigations of macro- and microstructure of glue-welded joints show that the structure of the molten metal of the nucleus of a high-quality spot, carried out by welding with a layer of EPTs and K 153 glues in no way differs from the structure of the nucleus of a spot carried out without glue. The microstructure of the nucleus includes two zones: external, consisting of columnar crystals, and internal – of equiaxial crystals.

The formation of the structure of the metal of the spot nucleus and on its form during welding with a layer of liquid glue is affected by the ability of glue to be pressed from the contact site; force and time of preliminary pressing of welded parts in cold state; amounts of welding and forging pressure; form and state of the contact surface of the electrodes; character of treatment of surface of parts for welding; state of welded surfaces (presence of flakes, scratches, grooves, etc.): type of filler in the glue and its viscosity, and others.

A great quantity of filler in EPTs glues promotes rapid build-up of its viscosity and, consequently, incomplete pressing from the contact site. Glue which is not pressed from the welding contact in the process of welding burns. Gases and slag thus formed

causes formation of pores, pits, and slag inclusions in the metal of nucleus of the spot (in the center of the nucleus and, in a number of cases, on its periphery).

Welding with EPTs glue with brief preliminary (cold) pressing of the metal by the electrodes of the spot welding machine (less than 1 s) or without preliminary pressing leads to the formation in the molten nucleus of the spot of slag inclusions disposed around the periphery of the molten zone and in the center of the nucleus. This is explained by the fact that the glue on an insignificant area in the center of the welding zone contact is not pressed out and partially burns when the current is switched on, being turned into slag. With sufficiently prolonged pressing of cold contact by a force 2-3 times exceeding the welding force, in combination with application of forging pressure, the glue is pressed more completely, thanks to which in this case formation of slag inclusions and porosity in nucleus of the spot does not occur.

Glue-welded joints carried out under optimum conditions with freshly prepared EPTs glue, and also at the end of its viability, did not reveal essential changes in the structure of the molten nucleus. This epoxy-cement glue in these cases is well pressed out from the contact site, and the epoxy resin brought by welding heating to high temperatures becomes partially a conductor of electrical current and therefore does not prevent the process of welding.

The process of welding with strongly thickening glue proceeds unsatisfactorily: there are observed strong splashing and distortion of the form of the spot nucleus; it is impossible to obtain stable diameter for it within prescribed limits. Forcing the conditions of welding by current, although it promotes lowering of the viscosity of the glue, however leads to unnecessary heating up of the contact surfaces of the parts and softening of them, increase in depth of fusion of the parts, and a decrease in diameter of the nucleus. An

attempt to increase the viability of EPTs glue by refreshing it with solvent (for example, dibutylphthalate) did not lead to positive results.

Use of the second technological variant for production of glue-welded joints with application of epoxy-cement self-setting glues of the type EPTs, EORTs, and K 153 turned out to be impossible, since the glues mentioned due to high viscosity possess bad penetrating and clearance-filling ability, and therefore do not ensure reliable filling of the clearances of the joint cavity.

A study of the penetrating and clearance-filling ability of these glues was conducted at first on welded samples of a technological specimen of alloys D16T and AMg6M with a thickness of 0.8-1.5 mm and on riveted samples. With one-sided introduction after welding of glues EPTs 1 or EPTs 2 into the clearance of the joint of sheets with a thickness $\geq$1 mm the lap cavity is filled to a width of not more than 9 mm, and a joint 1.5 + 1.5 mm thick, to 13 mm. Glues in initial composition have high viscosity and therefore are poorly squeezed from a hand pencil-gun. Use of a pneumatic gun, however, permits noticeably improving the feed of these glues into the lap clearance.

A more thorough study of the penetrating and clearance-filling ability of these glues was made on transparent samples (50·300 mm), where aluminum alloy AMg6M 1.5 mm thick was riveted with organic glass 2 mm thick, and also on regular riveted samples of alloys D16T and AMg6M (pack 1.5 + 2 mm). To eliminate the possible effect of air suction, certain transparent samples were simultaneously with the riveting glues on three sides around the perimeter of a border zone up to 10 mm in width with glue EPTs 1. Interval between rivets equalled 50, 75, and 100 mm. The aluminum and transparent plates prior to conjugation were subjected to thorough degreasing.

In the process of performing the experiments the lap clearance was measured with a gauge, which, for riveted joints carried out

with intervals of 50, 75, and 100 mm, composed respectively 0.15, 0.18, and 0.2 mm. The measured quantity of ready EPTs or EORTs glue, containing 50 parts by weight of cement was introduced by means of a pencil-gun manually into the clearance of the joint. To ease the flow of glue the samples were set at an angle of 25-30°. Depth of penetration of glue into the lap cavity of the transparent samples was observed visually through organic glass samples and also measured after specific intervals of time by a special rule.

Results of experiments (Figs. 14 and 15) visually show that EPTs and EORTs glues possess insignificant penetrating ability and therefore cannot ensure production of effective glued composite joints by the capillary method of applying the glue. Penetration of these glues into the joint cavity occurs to an insignificant depth only 15-20 minutes after their application to the edges of the overlap and then practically ceases. Thus, the depth of penetration of EORTs and EPTs glues into the lap cavity of samples with organic glass (interval of rivets 50 mm) in the first 5 min amounted respectively to 12 and 7 mm (Fig. 14), and after 10 min it was increased additionally 50% in all. A still smaller increase was observed after 15 min. After 20 min, the glues penetrated the joint clearance to a maximum depth (glue EORTs to 18 mm, EPTs - to 14 mm), after which their further flow into the lap cavity ceased.

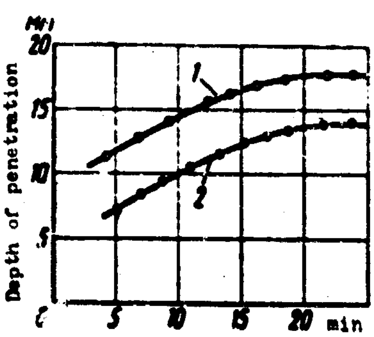


Fig. 14. Depth of penetration of glues EPTs and EORTs into the lap cavity of riveted transparent samples (with organic glass): 1 - glue EORTs; 2 - glue EPTs 1.

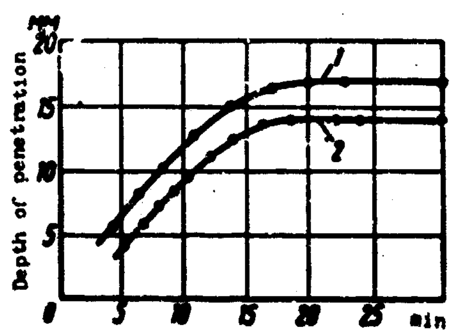


Fig. 15. Depth of penetration of glues EPTs and EORTs into the lap cavity of riveted aluminum samples: 1 - glue EORTs; 2 - glue EPTs.

Depth of penetration of these glues into the lap clearance of riveted aluminum samples in the first 5 min turned out to be considerably less (Fig. 15) than for samples with organic glass, which is caused, apparently, by the different wettability of surface of the materials mentioned. Then the rate of flow of the glues noticeably increased and after 20 min they had penetrated the clearance practically to that same maximum depth as in the case of the transparent samples.

Depth of penetration of glues into the cavity of riveted joints carried out with an interval of rivets of 75 and 100 mm, turned out to be insignificantly greater than with an interval of 50 mm.

Manufacture of Joints with the Use of Heat-Resistant Glues

The most promising for production of glue-welded joints from the point of view of high thermal stability are glues VS 10T, VS 350, VK 32-200 and VK 32-250. Testing of glues VS 10T and VS 350 in the production of glue-welded joints showed that in liquid form, in spite of good fluidity, they do not ensure uniform filling of the clearance in the lap cavity both in the case of welding with glue and also in the case of introduction of glue into the clearance of the joint after welding. Furthermore, the presence in these glues of a large quantity of solvent (dry residue 15-30%) causes bubbling, porosity, and friability in the glue layer, disturbing its continuity. When glue welding with both glues, in spite of relatively low viscosity, they are poorly pressed out from the contact site even with the application of considerable force of preliminary pressing. As a result of this, the process of welding is accompanied by splashing, and in nucleus of the spot by metallographic analysis there are revealed coarse slag inclusions.

Attempts to use these glues in the form of film on a fibre base did not give positive results due to great difficulties in

the selection of welding conditions, with which the force of compression of electrodes would ensure uniform pressing of the glue film around the spot weld. Due to nonuniform pressing, sections of the glue film directly adjoining the spot weld turn out to be under excessively great pressure and possess reduced strength, and the zone of film 25-30 mm away from the spot weld turn out to be nonglued. As a result, average strength during work under shear of the glue layer over the area of overlap does not exceed 20-30 kgf/cm^2.

For glues VS 10T and VS 350 a characteristic is lower strength during work under nonuniform breakaway, especially for glue-welded joints in connection with formation of inevitable nongluings in the boundary part of the overlap. Thus, glues VS 10T and VS 350 do not ensure high-quality glue-welded joints.

As experiments showed, glues VS 32-200 and VK 32-250 also cannot be used for production of glue-welded joints due to the necessity creating in the process of hardening the glue of high specific pressures (6-20 kgf/cm^2) on the glue layer. Glue-welded joints carried out by welding with liquid glue VK 32-200 or VK 32-250, and also by the method of introduction of glue after welding, according to strength indices practically did not differ from regular spot-welded joints. Furthermore, they did not possess airtightness due to considerable porosity in the glue layer induced by relatively large content of solvent in the glue.

Strength indices of glue-welded joints carried out by welding with glue film VK 32-200 turned out to be considerably higher than in the case of welding with liquid glue, but they strongly depend on the spacing of spot weld in the seam. Welding with film glue possesses a number of peculiarities and technological difficulties. Thus, the conditions of welding are selected from conditions of obtaining minimum and as stable as possible clearances between the welded sheets, and the thickness of the glue film used should exceed by 40-50% the value of given clearance. This permits, by means of obtained clearance to create sufficient pressing of the glue film around the spot weld.

Practically, with optimum welding conditions, for example welding of sheets with a thickness of 2 + 2 mm for normal polymerization of the glue film it is possible to obtain sufficient pressure around the spot weld only in a zone with a diameter of not more than 20-30 minutes. This sharply limits the selection of optimum spacing of spots and yet does not ensure high-quality and uniform gluing in the border zone of the overlap in which there are the most dangerous forces of nonuniform breaking stress [10].

The combination of welding with film glue VK 32-200 with subsequent application of epoxy glue on the edges of the overlap of the joint with the purpose of gluing the border zones promoted more uniform filling of the lap cavity, and the strength indices of the glue-welded joint in so doing turned out to be also comparatively low. Furthermore, the epoxy glue gave a porous layer, obviously, because of the release of gaseous components from the glue film.

Analogous unsatisfactory results were obtained and during technological testing in production of glue-welded joints of VK 32-250 film glue possessing practically the same properties as glue VK 32-200.

Thus, in connection with the unsatisfactory technological properties of standard heat-resistant glues VS 10T, VS 350, VK 32-200, and VK 32-250 it appeared necessary to search for and to develop new special heat-resistant glue compositions designed for production of glue-welded joints.

<u>Manufacture of joints with the use of glues VK 1 and VK 1M and VK 1MS</u>. Glue VK 1 possesses sufficiently prolonged viability and good fluidity, therefore glue-welded joints with this glue can be made according to both technological variants. The technology of welding with raw glue VK 1, and also with introduction of it into the clearance of the joint by the capillary method practically does not differ from similar processes with the use of glue FL 4S.

Expenditure of VK 1 glue in the manufacture of glue-welded joints does not exceed 200-250 g/m^2 of surface covered by glue.

Glue VK 1 fills clearances between combinable surfaces well, is easily pressed out from the contact sites under the pressure of the electrodes of the welding machine, and does not hinder the process of welding. Stability of the welding process and the quality of glue-welded joints was checked during welding on direct current pulse machines of the type MTPT 600 with variable pressure and alternating current machines of the type MTP 150.

Samples of alloys D16T and AMg6 (1.5 + 1.5 mm) were welded with glue and without glue. The quality of welding was estimated according to the character of cut and tearing of spot welds and according to the character of the microsection. In all cases, the process of formation of the welded joint proceeded firmly and stably. The presence of the glue does not affect the quality of the spot welds. Nucleus of the spots has identical assigned dimensions and correct form; the molten metal of the nucleus has no defects. Optimum conditions of welding with glue and without glue of samples differ essentially from each other (Table 61).

Table 61. Optimum conditions of welding of samples of alloy D16T (1.5 + 1.5 mm) on an MTPT 600 machine.

Parameters of conditions	Without glue	With a layer of glue
Welding current, in A	47 000	41 000
Duration of welding pulse, in s	0.17	0.09
Force of compression of electrodes, in kgf:		
welding	1100	1250
forging	2650	2800
Average diameter of nucleus spot, in mm	6.5	6.5

A positive property of VK 1 glue is also the fact that thanks to its considerable mobility and fluidity force of preliminary pressing of electrodes of the spot welding machine is not required.

The VK 1 glue does not cause corrosion in contact with plated and nonplated Duralumin D16T, and also alloy AMg6. Glue-welded samples (100 pieces) were held at a temperature of 20°C for 10 days, after which the welded spots were drilled and internal cavities of the samples uncovered. Here the glue was in viscous, nondry state and easily cleaned of solvent. No traces of corrosion of the metal under the glue layer were revealed.

Welding with a raw layer of VK 1 glue can be performed in the course 3 days from the moment of its application. Viability of the glue during the manufacture of glue-welded joints was determined according to the character of the course of the welding process and on conditions selected for welding with a layer of freshly prepared glue, and also according to the change in strength of joints depending upon time of open holding of the glue (Table 62). Tests were conducted on standard samples of D16AT (1.5 + 1.5 mm) with a drilled spot with overlap of 25·25 mm.

Table 62. Shear strength τ_B in kgf/mm^2 of glue-welded joints carried out with glue VK 1, depending upon duration of open holding.

Open holding after application of glue in h	Temperature of tests in °C				Character of course of welding process
	20	100	150	200	
0	185	186	88	22	Normally
24	152	170	119	27	Normally
[illegible]	150	132	134	31	Normally
72	151	162	106	32	Normally
96	209	202	257	28	Glue is thickened welding proceeds with splashing

From Table 62 it is clear that the duration of holding the glue up to 3 days after applying it to the mating surfaces practically does not affect the stability of the welding process and the strength of joints. The increase in strength of joints with drilled spot during holding for 96 h is explained, obviously, by the fact that in so doing the load is absorbed only by the glue layer, the strength and thermal stability of which is increased with the increase in time of open holding (Chapter IV).

Inasmuch as VK 1 glue has sufficiently high dry residue (99.44%), it practically contains no solvent and, consequently, during hardening does not release gas-forming components, and also has hardly any bubbling and shrinkage, which is the most valuable quality for glue-welded joints. In hardened state, the glue is sufficiently stable in standard active media and in electrolytes of sulfuric acid anodizing. It will form in glue-welded joints a sufficiently airtight layer, preventing penetration of electrolyte into the depth of seam during subsequent anodizing, zinc coating or other galvanic platings of glue-welded joints of Duralumin and steel.

The protective properties of the glue and its ability to hermetically seal clearances of glue-welded joint against flow of electrolytes during anodizing was checked on glue-welded samples made from plated D16T with dimensions of 200·40·2 mm with welded cover plate with dimensions of 180·30·2 mm, and panels 800·450·2 mm, consisting of sheathing and profiles of D16T. Interval between spots in all cases equalled 30 mm. One batch of samples was welded with a layer of glue, on the other batch the glue was applied by the capillary method after welding. A batch of samples was also made with application of glue containing 6% lead powder, introduced for determination of the degree of filling of glue of joint clearances by means of X-ray radioscopy. Before the tests, the samples and panel were subjected to anode oxidizing with filling in dichromate. Samples were tested for corrosion in a chamber with salt water spray (3% NaCl) for 4 months, and in a tropical climate chamber for 3 months.

After drilling the spots and dissection of the welded seams on samples and panels no traces of corrosion, peeling of glue and flow of electrolyte inside the seam were revealed. Introduction of 6% lead powder into the glue does not impair the protective properties and corrosion resistance of glue-welded joints.

High strength and thermal stability up to 150°C of glue-welded joints with VK 1 glue in the absence of hardening, and also the good technological properties of VK 1 glue make this glue very promising for application in glue-welded constructions.

However, the tendency of VK 1 glue to obtain lower viscosity during hardening at a temperature of 100-110°C and, due to this to emanate from the joint clearances (Chapter I) limits the region of its use in glue-welded articles having considerable curvature or subjected to polymerization at considerable angles of inclination to the horizontal. This deficiency can be eliminated by increasing its viscosity by means of preliminary preheating. Preliminary open holding of parts with an applied layer of VK 1 glue at a temperature of 80°C decreases spreading of the glue layer. Since open holding of glue in glue-welded joint is impossible, it is necessary to heat the glue at a temperature of 80°C for 1 h 15 min prior to pouring it into the clearance of the joint. Shorter holding does not lower the spreading ability of the glue, and an increase in holding leads to difficulty in filling the clearance with glue.

Glue which is preliminarily heated according to conditions mentioned well fills the clearance of the welded joint with a width of overlap up to 38 mm and will not form leaks with a slope of the article in the heating device to 30°C, inclusive. At large angles of inclination of the article, especially with increased clearance in the joints, in separate cases glue leaks can appear. Repeated heating of the glue at 60°C for 1 h reduces the strength of the joint and cannot be recommended (Table 63).

Table 63. Shear strength σ_B in kgf/cm^2 of glued-weld joints of D16T with drilled spot, depending upon the state of glue VK1 and its polymerization conditions.

State of glue at the moment of its introduction in the joint	Temperature of polymerization in °C	τ_B
Glue of usual viscosity (without preheating).......	80 155	$\frac{166}{144-179}$
Glue, preheated at 80°C for 1 h 15 min.............	120 155	$\frac{141}{137-147}$
Glue, preheated at 80°C for 1 h 15 min, and then again at 60°C for 1 h	120 155	$\frac{111}{108-113}$

Flow of VK 1 glue from the clearances of the joint during its hardening can also be prevented, for example, by gluing around the contour of the overlap after application of glue with sticky tape, insulating tape, and so forth. But this method is very labor-consuming and carried out only manually, and therefore is basically suitable for experimental production.

More rational is the method of two-layer application of glue, at which the first layer, filling the overlap of the joint by capillary method, consists of glue VK 1, and the second layer, forming a bead, - of glue, rapidly drying in air with the formation of a dense film and thereby preventing outflow of VK 1 glue. For the second layer the most suitable is heat resistant glue VK 32-200 in liquid consistency (Chapter I). This glue, applied by brush or gun on the edge of the lap with preliminarily applied glue VK 1, dries rapidly and will form an even, smooth layer, preventing outflow of VK 1 glue from the cavity of lap at any position of the article during polymerization. Experimental panels under production conditions were subjected to polymerization in horizontal position, and also at angle 30, 45, 60 and 90°.

In all cases no blotches of glue were observed from the cavity of overlap. As the second layer it is technologically permissibly

to use glues of the type FL 4S and K 153. But they, due to low thermal stability, limit the overall thermal stability of the joint obtained, which in a number of cases is impermissible. A deficiency in this method is the considerable labor-input and the necessity of application of different grades of glues to one article.

Glue VK 1M possesses reduced viability and fluidity, therefore the manufacture of glue-welded joints can sometimes be performed according to the second technological variant, with which glue is introduced into the clearance of the joint after welding.

In the case of welding with a layer of VK1M glue the latter because of lowered fluidity is poorly pressed from the contact sites as a result of which the process of welding proceeds insufficiently firmly and stably, in the nucleus of the spot there will be formed slag inclusions and other defects. With one-sided introduction of VK 1M glue into the joint clearance after welding there is ensured reliable filling of the lap cavity with a width of 18 mm in approximately 2 h and during bilateral - with width of 35 mm after 1.5-2 h.

After introduction of glue, the welded article must be held at 20°C for 18-20 h, then placed in a cold furnace, where gradually the temperature is increased to 100°C, at which hardening of the glue occurs in 3 h. The conditions given are tentative. Increase of content of solvent in the glue contrary to nominal (see Chapter I) by only 5% requires correction in the conditions of hardening it in order to avoid the appearance of porosity in the glue fillet.

As the experiments showed, with a change in furnace of angle of inclination from 20 to 90° of the glue-welded panels with dimensions of 800·450 mm there are observed not even traces of flow of glue VK 1M from the joint clearances. This makes it possible to use this glue in constructions in any attitude.

Glue VK 1MS possesses the best technological properties as compared to glues VK 1 and VK 1M. Its comparatively long viability and insignificant viscosity permit preparing a glue-welded joint with this glue by both technological variants. In the case of introduction of glue VK 1MS into the joint clearance after welding, its penetrating ability depends on the amount of clearance between the elements being joined (thickness of the sheets), viscosity of the glue, and the temperature of the working site. With one-sided introduction of glue and a temperature of 18-20°C there is ensured reliable filling of the lap cavity with a width of 18-20 mm with bilateral - a width of 45-60 mm in 1.5 h from the moment of preparation of the glue.

Experiments were conducted on samples made of Duralumin D16T with combination of welded thicknesses from 3 + 3 to 0.4 + 0.4 mm. Even during welding of parts of small thicknesses, when the clearance between combinable elements exceeds 0.08-0.1 mm, glue VK 1MS ensures complete and continuous filling of the joint clearances. The most uniform and dense layer of glue (without bubbles and times) fills the cavity of overlap during welding of parts of great thicknesses ($\geq$1 mm), which guarantees the airtightness of such glue-welded joints.

Welding with a layer of glue VK 1MS is possible within 5-8 h from the moment of its preparation. Inasmuch as open holding reduces the viability of the glue, then it is necessary to combine the surfaces as quickly as possible after its application. Thanks to comparatively long viability and insignificant viscosity, glue VK 1MS is well squeezed out from the contact site under the impact of the welding force of compression of the electrodes. Welding within limits of the period of viability of glue VK 1MS proceeds firmly and stably, and does not cause defects in the spot nucleus. Within 8-10 h from the moment of preparation and application of the glue there begin to appear insignificant slag inclusions in the spot nucleus observable only by microscopic examination.

Samples from alloys D16T and AMg6 with thickness of 1.5 + 1.5 and 2 + 2 mm were welded on an MTPT 600 machine with variable pressure graph. After hardening, the glue layer of VK 1MS becomes sufficiently [illegible]se and uniform, and without signs of shrinkage. However, in a number of cases in the glue layer individual blowholes are caused as a result, apparently, of incomplete removal of products of combustion of the glue in the resistance welding zone during passage of the current. As a check showed, these individual defects do not disturb the airtightness of the glue-welded joint.

Manufacture of joints with the use of glue VK 7. Manufacture of glue-welded joints with the use of glue VK 7 is possible by both technological variants. However, best results are given by the second variant, with which glue is introduced into the joint clearance after welding. Testing of VK 7 glue in glue-welded joints was produced on different samples and experimental panels from alloy D16T with thickness of 1.5 + 1.5 and 2 + 2 mm and stainless steel of austenite-martensite class of type SN with thickness of 1.2 + 1.2 mm. Samples and panels were welded on an MTPT 600 machine with direct current pulse and on an alternating current MTP 200 machine.

Thanks to very long, working viability and comparatively low viscosity, glue VK 7 possesses good penetrating ability. Thus, during one-sided introduction of it into the clearance of a single-row joint with a thickness of 1.5 + 1.5 mm there is ensured reliable filling of an overlap with a width of 25 mm, and during bilateral – with a width of 45-50 mm. During bilateral introduction into the clearance of a two-row joint with checkerboard location of spot welds, this glue penetrates to a depth of 40-45 mm reliably filling the whole cavity of overlap. There is observed equally good outflow of VK 7 glue from the nozzle of the pencil-gun both directly after preparation and also after twenty-four hours.

In the composition of glue VK 7 there is up to 35-40% solvent (ethylcellosolve), which leads to a somewhat porous structure of glue seam and complicates the condition of welding with a layer of

glue. When welding with glue, in spite of the relatively low viscosity, it is poorly squeezed out from the contact site even with the application of considerable force of preliminary pressing. It is practically impossible to select optimum conditions of welding ensuring full pressing out of the glue from the zone of the welding contact. However, the presence in the welding contact of a glue film does not prevent the process of welding, which is borne out by the absence of formation of splashing and the stable formation of the molten spot nucleus of assigned dimensions and form.

By metallographic analysis, in the spot nucleus there are revealed coarse slag inclusions of round and other forms (Fig. 16), which will be formed as a result of combustion of nonpressed glue residues in the welding contact during switching on of current. Similar defects in the spot nucleus most frequently lower the efficiency of welded joints during cyclical loads and practically do not affect the static strength of these joints. However, as evident from Table 68, static shear strength of glue-welded joints carried out with a layer of glue VK 7 turns out to be considerably lower than in case of introduction of glue into the joint clearance after welding. For the purpose of establishing the causes of this phenomenon monospot glue-welded samples of D16T were subjected to comparative shearing tests (carried out with layer of glue) with an unhardened glue layer and usual welded thicknesses of 2 + 2 mm, with diameter of spot of 7-7.5 mm.

Average breaking load of the usual welded spot composed 780 kgf and the spot carried out with a layer of glue VK 7 (glue is not hardened), 665 kgf. Samples were destroyed in both cases due to shearing of the nucleus of the weld spot. However, destruction of the spot nucleus carried out with a layer of glue (in contrast to destruction of the usual spot) took the form of brittle fracture, and the macrostructure of the metal of the nucleus of such a spot bore a macrocrystalline character; in microstructure of this metal there were observed very big slag inclusions. Spectral analysis of surface of fracture showed traces of titanium. This permits

assuming that titanium dioxide (the glue filler) during welding heating in zone of formation of the spot nucleus is decomposed and chemically interacts with the melted metal of the nucleus forming a fragile intermetallic compound of reduced strength.

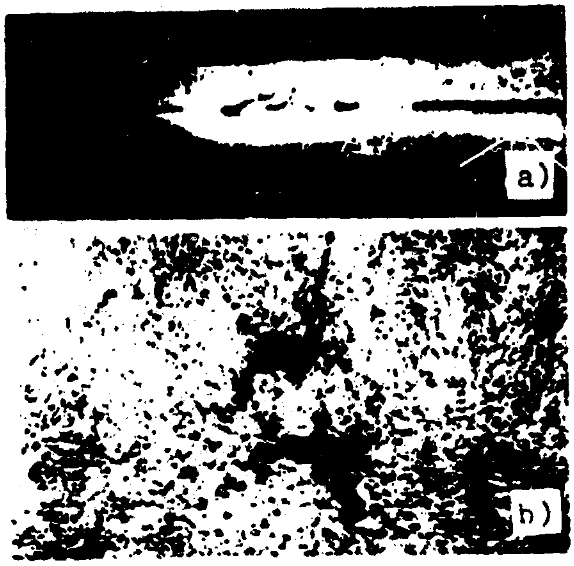


Fig. 16. Macrostructure of spot nucleus (a) and microstructure (b) of transition zone during welding of alloy D16T with a layer of glue VK 7.

One of basic requirements imposed on glue utilized for the production of glue-welded joints is ability of the glue to harden during minimum (desirably "contact") pressure on the joint. In connection with this, there was studied the influence of pressure during gluing with VK 7 glue on strength of the obtained glue joints (Table 64). From Table 64 it is clear that a change in pressure during gluing within rather wide limits practically does not render an effect on the strength of the glue joints, where the increase in pressure in separate cases even leads to a certain reduction of strength indices. These data testify to the very valuable qualities of VK 7 glue, opening wide possibilities for its use for production of glue-welded joints, especially when performed by the capillary method.

A content of up to 35-40% solvent can lead during hardening of glue VK 7 in a glue-welded joint to the appearance, in a number

of cases, of porosity in the glue layer. Therefore it is more rational to use the step graph of heat treatment of glue-welded joints with which there is attained the best airtightness of the seam. Thus, for example, in the manufacture of glue-welded joints from naturally aged plated Duralumin D16T with thickness of 0.8 mm and more, it is possible to recommend the following conditions of heat treatment: 1) holding at 20°C, 24 h; 2) increasing temperature to 60°C during 1 h; 3) holding at 60°C, 2 h; 4) increasing temperature to 180°C and then holding (hardening the glue) during 2 h, or increasing temperature to 150°C and holding 5 h, or increasing temperature to 120°C and holding 12 h.

Table 64. Shear strength τ_B in kgf/cm^2 of joints of Duralumin D16T (1.5 + 1.5 mm) on VK 7 glue depending upon pressure during gluing.

Pressure during gluing, in kgf/cm^2	Test temperature in °C		
	20	230	250
Contact	88 75—106	75 67—84	19 18—20
0,5	87 76—108	83 57—113	26 16—36
1	94 90—95	46 36—55	19 15—23
3	91 82—101	51 43—60	17 12—20
5	86 79—104	56 50—69	19 16—23

The glue layer after the heat treatment mentioned ensures sufficiently reliable hermetic sealing of the clearances of the glue-welded joint from the flow of electrolytes used during different forms of anodizing aluminum alloys, protection from corrosion of the mating surfaces, and is also resistant to the action of the mentioned electrolytes, acetone, aromatized gasoline, T2 fuel, kerosene, and oils. The protective properties of the glue and

reliability of hermetic sealing was checked on samples of alloy D16T with dimensions of 200·40·2 mm with welded cover plate from plated and nonplated alloy and panels 150·300·1.5 mm with welded on bracing elements with interval between spots of 30 mm. Glue was introduced after welding by the capillary method. After heat treatment of the glue, samples and panel were subjected to anodizing with filling in dichromate, and then corrosional tests for 2 months in a chamber with salt water spray (32% solution of sodium chloride) and in a tropical climate chamber. After the tests, the samples and panel had not a trace of flow of electrolyte inside the seam, no traces of corrosion of metal and peeling of glue.

Chemical resistance of the glue in electrolytes and its adhesion to metal with various thickness of glue layer and different state of surface of alloy D16T were checked on samples of a technological specimen (packs 1.5 + 1.5 and 2 + 2 mm), and also on sample-billets in the form of strips 150·40·3 mm, having on one side a longitudinal groove 100·15·1 mm milled through, in which there was applied glue in different thicknesses. On the reverse side of these samples there was also applied by brush a thin uniform glue layer. After polymerization of the glue, all samples were subjected to anodizing in sulfuric acid with filling of film in dichromate. One batch of glue-welded samples (5 pieces) and part of the sample-billets (5 pieces) were subjected to repeated anodizing with preliminary removal of the anode strip by etching in a 5% solution of sodium hydroxide at a temperature of 60°C for 2-3 min. The state of the glue fillet and layer after etching and anodizing remained unchanged. The glue proved to be stable in all media both during single and also during repeated anodizing.

Testing of VK 7 glue and also other heat-resistant glues in the production of glue-welded joints made of heat-resistant, stainless steels of SN type did not give reassuring results since the glues have poor adhesion to the surface of the shown steels mentioned. Introduction of glue into the welded joint increases its strength by only 5-12%. Here the destruction of the glue layer

bears a sharply expressed adhesional character, there is observed peeling of the glue from the surface of the metal. Attempts to increase adhesive ability of glue by means of various preparations of the surfaces to be glued (chemical etching, sand blasting, hydroabrasive and shot-blasting treatment, stripping with a brush and abrasive wheel, and others) did not give positive results.

The technology of manufacturing glue-welded joints with the use of VK 7 glue is useful for large-dimension structures made from aluminum alloys. Because of high heat resistance, glue VK 7 can be used in a number of cases as well as for production of thin-sheet glue-welded constructions made from steel and titanium alloys, to which it has increased adhesion and ensures airtightness of the joints.

<u>Manufacture of joints with the use of glue VK 9</u>. Glue VK 9, thanks to high heat resistance and satisfactory technological properties is a prospect for production of glue-welded joints. The basic method of joining is welding with liquid or paste-like glue.

The possibility of welding with a layer of glue VK 9[1] was studied on samples and panels from alloys D16T and AMg6, with thickness in pack of 0.4 + 0.4; 0.5 + 0.5; 1 + 1; 1.2 + 1.2: 1.5 + 1.5 and 2 + 2 mm. Welding was performed on MTPT 400 and MTPT 600 machines with use of preliminary pressing and without it directly after preparation and application to the mating surfaces of glue, and also after holding for 1-2 and 3 h the glue applied to the samples. Preparation of the surfaces of samples and panels here was carried out by following flow diagram: 1) rubbing with acetone for the purpose of removing fatty lubrication, marking paint, and other contaminations; 2) degreasing for 5 min in a solution of the following composition: 100 g/l sodium hydroxide, 20 g/l soda ash at a temperature of 60-70°C; 3) purification in a 20% solution of nitric

[1]Glue VK 9 in accordance with Republic technical specifications contained filler in a quantity 5 parts by weight.

acid with subsequent washing in hot and cold water; 4) stripping with a wire brush.

The process of welding directly after application of the glue, and also within 1 h after this proceeds steadily, with stable formations of spot nucleus (Fig. 17). In case of welding within 2 h after application of glue, splashing is not observed, but along the border of the spot nucleus there is formed insignificant slag inclusions, disturbing the homogeneity of the molten metal. For 3 h after welding it is not possible to obtain a high quality welded joint. Here there is observed splashing, in the spot nucleus there is intensively formed slag inclusions, pores and cracks (Fig. 17c). In case of welding of parts of small thicknesses with glue VK 9, even after 1.5-2 h after its application there will be formed annular fusion (Fig. 17b), and then complete nonfusion. When welding with glue VK 9 at the end of the period of its viability there occurs intense burning out of glue along the boundary of the nucleus (sometimes accompanied by splashing), causing the formation of gas pores and bubbles in the glue layer during its hardening. Therefore, when welding with glue VK 9 it is necessary to observe more strictly the time from the moment of application of glue to the completion of welding of the subassembly to avoid the formation of an unrepairable reject article.

Thus, it is possible to recommend welding with a layer of VK 8 glue parts with a thickness of $\geq$1 mm within 2 h from the moment of preparation and application of the glue, and parts of smaller thicknesses - within 1 h and 15 min.

Hardening of glue in glue-welded joints occurs practically completely in the course of a few days at a temperature of 18-23°C. The process of polymerization of glue can be accelerated, using preheating to 60°C in 1 h. In the process of hardening glue at room temperature there does not occur separation of volatile substances. However application of glue to surfaces of parts to be welded is recommended to be produced in a location with intake-exhaust ventilation. Expenditure of VK 9 glue in glue-welded

joints averages 250-280 g/m^2. With an increase in quantity of filler, the expenditure of glue is increased.

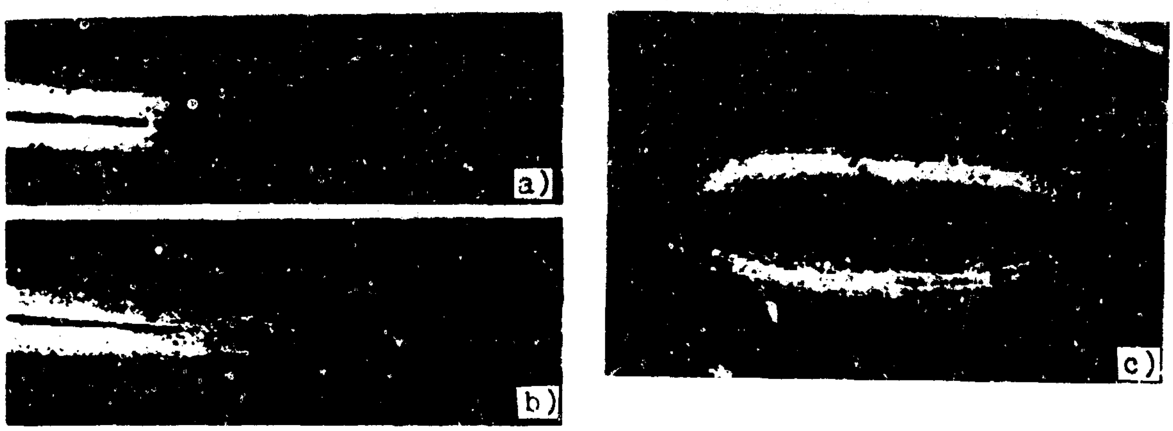


Fig. 17. Macrostructure of spot nucleus in the welding of alloy D16T with a layer of glue VK 9: a) directly after application of glue; b) within 2 h after application of glue; c) within 3 h after application of glue.

Experiments showed that character of the course of the welding process with glue VK 9 depends strongly on the quantity of filler (aluminum powder) in it. In connection with this, for optimum conditions there were welded with glue with varying quantity of filler, samples from alloys D16T, D16M, AMg6 and AMgAP in thicknesses of 1-2 mm; they were welded after 5, 15, 30, 60, and 120 min after preparation and then with open and covered holding of the glue applied to the samples.

The process of welding with glue VK 9 containing 3 parts by weight of filler proceeds in all cases firmly, with stable formation of spot nucleus. The glue is well pressed out from the contact site even in case of application of very slight force of preliminary pressing (approximately equal in value to welding force). Thanks to the presence in the glue of a small quantity of filler, in the glue-welded joint there is formed a very thin glue layer (~0.05 mm), which promotes an increase in strength of the joint. Furthermore,

such glue is easily and evenly applied not only by spatula but also with a brush, and also by the method of pneumatic squeezing. However, lowering the quantity of filler in the glue noticeably increases the price. An increase in the quantity of filler in the glue to 5 parts by weight somewhat increases its viscosity, but does not render a negative effect on the process of welding. Thus, the successful conduct of welding with such glue of samples in thickness of 1 mm and more with application of force of preliminary pressing exceeding 1.5 times the welding force turned out to be possible within 2 h from the moment of preparation and application of the glue with covered holding and within 1.5 h with open. In so doing, the glue just as in the preceding case is easily and evenly applied with a spatula and brush in a transparent thin layer, which permits revealing the structure of the surface of samples prepared for welding, the presence on it of grooves, scratches, and other possible defects.

Good results were also obtained when welding with a layer of VK 9 glue with content of filler of 8 parts by weight. With an increase in the content of filler to 10 parts by weight the viscosity of the glue noticeably increases, it obtains a paste-like state. Here its ability to be pressed out from the contact sites noticeably descends and also the process of preparation of glue under industrial conditions is complicated. Thus, there occurs intensive spraying of the aluminum powder during displacement of components under the impact of suction ventilation, there is required increased force for thorough mixing of the glue composition, etc. To prevent spraying of the aluminum powder it is recommended that glue VK 9 be prepared in closed vessels – glue mixers.

Paste-like VK 9 glue with filler content of 10 parts by weight, in contrast to other paste-like glues, is very well and evenly applied by spatula to the surfaces of parts to be welded. Welding with a layer of paste-like VK 9 glue containing 10 parts by weight of filler can be performed only with the use of increased force

of preliminary pressing with covered holding up to 1.5 h. With open holding, paste-like glue quickly builds up viscosity, which shortens its viability and promotes the formation of defective spots during welding. Thus, with welding after open holding of near 1 h, in the nucleus of the spot there will be formed considerable slag inclusions.

An especially important role in welding with glue VK 9 containing 10 parts by weight and more of filler is played by the quality of preparation of the surfaces to be welded. The most rational is a thorough degreasing and then chemical etching of surface of the parts. In this case the glue is well and evenly applied with a spatula in a thin layer over all the surface to be welded and preserves its viability longer during covered holding. Presence of separate insufficiently thoroughly cleaned sections of surface (during mechanical stripping) excludes the possibility of applying a uniform and thin layer of glue, lowering the quality of welding.

Welding with paste-like VK 9 glue containing 15-18 parts by weight of filler is very labor consuming and practically unprofitable. After covered holding for 15-20 min the glue becomes so viscous (resembling putty) which is quite poorly pressed out from the contact site even with strong force of preliminary pressing (exceeding by 1.5-2 times the forging force). Process of welding thus is accompanied by splashing and strong release of gases; in the spot nucleus there will intensively be formed slag inclusions and pores. Furthermore, the glue because of high content of filler is poorly and nonuniformly applied to the surfaces to be welded, which leads to formation of considerable local bulges in the glue layer and even clusters of glue. In process of welding there occurs strong overheating (sometimes burns) of separate sections of the article and, as a result of this, dilution and then emanation of glue from the joint cavity. The emanating glue falls on the surface of the parts and electrodes, which causes additonal overheating of welding zone, burns, and also requires frequent stripping of the electrodes.

Thus, on the basis of investigations conducted, it is possible to recommend for production of glue-welded joints, the use of VK 9 glue with a quantity of filler of 5-8 parts by weight. In the manufacture of glue-welded joints by the second variant, glue VK 9, as a result of high viscosity, has poor penetrating ability and, consequently, cannot completely fill the lap clearance. Thus, with one-sided introduction of it into the clearance of the joint after welding of parts with a thickness $\geq$1.5 mm there is ensured filling of the lap cavity with a width of not more than 5-7 mm.

Economic Effectiveness of Production of Glue-Welded Joints

Along with high strength and operational characteristics, glue-welded joints have an advantage over other forms of joints in respect to technical economic indices. Spot welding with modern equipment is an automated and very productive process. The absence of a whole series of auxiliary operations and materials (manufacture of rivets, drilling, and countersinking of holes, etc.) reduces still more the prime cost of manufacture of structures. The absence of some additional joining elements improves the weight characteristics of the structure and permits obtaining durable joints with minimum possible weight.

As an example we will use the data obtained during the calculation of labor-input and prime cost of manufacture of welded and riveted joints from alloy D16T with thickness of 1.5 + 1.5 mm (Table 65).

Table 65. Labor-input and primecost of manufacture of welded and riveted joints.*

Type of joint	Time of setting of one spot, in minutes	Primecost of setting of one spot, in rubles
Welding of parts of aluminum alloys on a spot welding machine	0,12	0,0021
Mechanized drilling and group pressing of riveting	0,31	0,0023
Hand drilling and single pressing of riveting	0,43	0,00256
Hand drilling and riveting	0,76	0,00371

*Nonhermetic riveting.

Modern constructions used in transport machine building, construction, must be airtight, therefore it is expedient to compare a glue-welded joint with a hermetically sealed riveted one. Calculations show that the additional labor-input and primecost of process of introduction of glue during the manufacture of glue-welded joints are considerably less than analogous indices of hermetic sealing of riveted joints (Table 66).

Table 66. Labor-input and primecost of manufacture of constructions by various methods of joining.

Type of joint	Primecost of manufacturing 1 m seam, in %	Relative indices of manufacturing 1 m seam, in %		
		Labor-input	Prime-cost	Weight
Spot welding	0,0693	100	100	100
Spot welding with use of glue (glue-welded joint)	0,0815	151	179	110
Mechanized drilling and group pressing of riveting (nonhermetic)	0,0845	175	123	103,5
Mechanized drilling and group pressing of riveting with surface hermetic surface	0,1667	385	242	143,5
The same with intraseam hermetic sealing	0,2029	560	290	123,5
The same with two-zone hermetic sealing	0,2852	784	406	168

From the examples given it is clear that the labor-input in the manufacture of 1 m of glue-welded seam in panel constructions of the frame type is 5.2 times lower than the labor-input of riveting with the most reliable two-zone hermetic sealing and (accordingly) is 3.7 and 2.5 times lower than the labor-input of riveting with intraseam or surface hermetic sealing.

Even nonhermetic riveting, which absolutely is noncompetitive with glue-welded joints in strength and airtightness requires 20% more labor expenditure than welding with the use of glue. In comparative calculation there were used indices of the most modern variant of riveting works - drilling on multispindle semiautomatic drilling-countersinking installations and group pressing of riveting.

In the majority of enterprises there predominate less mechanized methods of drilling and riveting, which makes the effectiveness of their replacement by glue-welded joints still greater.

Primecost of manufacturing 1 m of seam by spot welding with the use of glue is 3.4 times less than riveting with two-zone hermetic sealing (or 2.5 times less than with intraseam hermetic sealing and 2.1 times – with surface).

For structures of large dimension (especially in transport machine building) the weight of the article has great significance. With hermetic riveting the additional overweight on 1 m of seam as compared to glue-welded joints composes 58; 33.5 or 13.5 g (depending upon the hermetic sealing method).

In modern constructions, the extent of seams is measured in many hundreds of meters, and at the expense of replacement of hermetic riveting by glue-welded joints it is possible to considerably decrease the weight of an article, which frequently permits a sharp improvement in its operating characteristics.

In the manufacture of constructions from aluminum alloys welded by fusion welding, the replacement of joints carried out by argon arc welding by glue-welded joints can also be sufficiently effective. In so doing warping of welded subassemblies and very labor-consuming operations of correction and finishing practically are excluded; furthermore, the process of strictly welding also becomes more economical. Thus, for example, according to I. T. Kozlov [12], in the manufacture of welded constructions made from alloy AMg6 in railroad car construction there can be achieved the following economic indices (Table 67).

The data in Table 67 show that the primecost of the process of manufacturing glue-welded joints composes 30-76% as compared to argon arc welding of structurally similar elements. If one were

to consider that with argon arc welding of large dimension thin-sheet frame constructions there are inevitable considerable warping and very labor-consuming operations of correction, then the total technical economic effect from the use of glue-welded joints increases 2 times and more as compared to the data in Table 67.

Table 67. Comparative economic indices of welded and glue-welded joints.

Combination of thickness in mm	Variants of joints		Expenditure for 1 m seam, in kopecks		Relative expenditure for glue-welded joint, in %
	Argon arc welding	Glue-welded	Argon arc welding	Glue-welded	
3+3	Single-pass butt	Single-row lap	69,783	25,946	37,1
	Two-way butt		102,234	25,946	25,4
	Single-pass butt	Single-row butt with sheet cover plate	69,783	53,166	76,1
	Two-way butt		102,234	53,166	52
2+2	Single-pass butt	Single-row lap	51,859	22,224	42,8
	Two-way butt		75,699	22,224	29,3
	Single-pass butt	Single-row butt With sheet cover plate	51,859	39,453	76
	Two-way butt		75,699	39,453	52,1

Thus, glue-welded joints are not only more durable, more reliable and long-lasting than other types of permanent joints, but are also considerably more economical, which makes them very promising for application in different branches of machine building.

C H A P T E R IV

STRENGTH OF GLUE-WELDED JOINTS

General Information

Strength characteristics are the most important criteria in appraisal of the quality of connections since on them depends the reliability and period of work of a construction. Considerable influence on these characteristics is rendered by technological and design parameters of connections. Strength of a combined (glue-welded and glue-riveted) connection depends on the technology of its manufacture and properties of materials used (basic metal and glue) to a considerably greater degree than strength of a usual welded or riveted connection. Questions of strength, technology and properties of material during manufacture of combined connections are especially intimately interconnected. Therefore strength, rigidity and wearability of combined connections should be examined as a result of joint work in welding of combinable sheets (components), power points (welded points, rivets, bolts) and the glue layer.

Usual spot weldings of connections do not yield to riveted in reliability and strength. However, inevitable local concentrations of stress at the periphery of the nucleus of a welded point, especially in lap connections with working (power) points, leads to comparatively low cyclical strength (approximately identical with the strength of riveted connections).

In glue connections the load is distributed more uniformly in their section than in those welded or riveted, which leads to a sharp lowering of local concentration of stress and, consequently, to a noticeable increase in the cyclical strength of these connections. However, glue connections, having high shear and breaking strength characteristics, badly sustain the joint action of bending and breaking loads (i.e., badly work under conditions of nonuniform breaking). Furthermore, a change of strength indices is possible with the flow of time (aging).

Glue-welded joints at-most combine many advantages of welded and glue connections and remove deficiencies inherent to them. The presence of the glue layer in such a connection leads to a more equal distribution of stress in the section of overlap, lowers local concentrations of stress and creates the prerequisite for a considerable increase in cyclical strength of the connection. In turn, the welded point somewhat unloads the glue layer and increases its efficiency in breaking loads, especially under conditions of nonuniform breaking. Unfortunately, it is fairly difficult to create conditions for simultaneous inclusion of welded points and a glue layer during the action of loads under conditions of nonuniform breaking.

Static Shear Strength

The glue layer in welded point connections essentially increases its strength under static shear. This especially pertains to special constructional glue possessing good adhesion to metals. During loading of a glue-welded point connection by a stretching force the glue layer grasps a considerable part of the stress, unloading the welded point and promoting an increase in its efficiency.

Experimentally investigated was shear strength of glue-welded joints on samples made from alloys D16T, AMg6 with application of different, basically new glues and technology of their use. Comparative tests at usual temperature were conducted on monopoint overlapping samples carried out without glue with its subsequent application and

polymerization, and also welded by a layer of liquid glue and then consolidated in optimum (for the given glue) temperature conditions. Control samples were prepared without glue. For certain appraisals of the additional strength created by the glue layer, also tested were glue-welded samples with drilled welded points. Furthermore, the efficiency of glue-welded joints was studied on different monopoint samples carried out with application of heat-resistant glue VK 7, at raised temperatures. Results of tests are given in Tables 53, 54, and 68-71. Monopoint glue-welded samples were destroyed basically in the plane of the connection.

Data of Table 53, 68 and 69 show that shear strength glue welded connections in conditions of usual temperature in all examined cases is noticeably higher than strength of monotypic welded joints. For a smaller thickness of joined sheets the effect of application of any shown glue is considerably higher than for greater thickness, which agrees with data obtained earlier [10]. This is possible to explain by the fact that glue gives great rigidity to thin sheets, changing the character of the distribution of stress through the section of the connection (levelling). Furthermore, the area of the zone of gluing with respect to the area of the nucleus of the welded point on thin sheets is somewhat larger, and the glue layer has smaller thickness, caused by the very small clearance between sheets (close to the optimum clearance of usual glue joints) and, consequently, better strengthens the welded joint.

Analysis of source material, and also study of the change in shear stress of the glue layer depending on thickness of joined sheets on glue and glue-welded joints with application of glues KLN 1 and EPTs 1 showed that if in a glue connection shear stress grows with an increase in thickness of glued sheets, then in glue-welded, conversely, then is observed a rather sharp drop in sheer stress of the glue layer. Obviously the biggest influence on such a character of change of stress is rendered by the essential increase in thickness of the glue layer in glue-welded joints, connected with the inevitable

Table 68. Shear strength of connections of Duralumin D16T (overlap 25 × 25 mm).

Glue	Method of fulfillment of glue-welded joint	Combination of thicknesses in mm	Diameter of nucleus of point in mm	Breaking load in kg
Without glue	–	0,6+0,6 1+1 1,2+1,2 1,5+1,5 2+2	3,5 5 5,5 6,5 7,5	130 240 320 510 655
VK 7	Application of glue after welding	1,5+1,5 2+2	6,5 7,5	585 1066
	Welding on glue	2+2	7,5	745
VK 1MS	Application of glue after welding	0,6+0,6 1,2+1,2 2+2	3,5 5,5 7,5	625 755 1000
	Welding on glue	2+2	7,5	1045
VK 1	Application of glue after welding	0,6+0,6 1,2+1,2 2+2	3,5 5,5 7,5	615 725 1025
	Welding on glue	2+2	7,5	1005
KLN 1	Application of glue after welding	1+1* 1,5+1,5* 2+2 1,5+1,5	5 6,5 7,5 6,5	490 560 795 595
	Welding on glue	1,2+1,2 1,5+1,5 2+2	5,5 6,5 7,5	520 575 770
K 153	Welding on glue	1,2+1,2 1,5+1,2 2+2	5,5 6,6 7,5	460 545 765
EPTs 1	Welding on glue	1,5+1,5 2+2	6,5 7,6	550 780
VK 9	Welding on glue	1,5+1,5 2+2	6,5 7,6	590 820
FL 4S	Application of glue after welding	0,6+0,6 1,2+1,2 2+2	3,5 5,5 7,5	470 575 915
	Welding on glue	0,6+0,6 1,2+1,2 2+2	3,5 5,5 7,5	415 545 900

*Overlap 20 x 20 mm.
[Translator's Note: no asterisk found in table.]

increase in the clearance between welded sheets according to the increase in their thickness. A defined influence is rendered probably by the increase in bending (breaking) loads in limb zones of overlap on amount of the increase in eccentricity of application of the load with an increase in thickness of test samples. According to work [10], the shown breaking loads appear considerably stronger in glue-welded joints than in glue of joints.

Table 69. Strength of connections* of aluminum alloys (welding on liquid glue EPTs 1).

Welding alloys	Combination of thicknesses in mm	Joint	Diameter of nucleus of point in mm	Average shear breaking load in kg	Ratio of shear strength of welded joint to strength of glue-welded joint in %
AMg6M + AMgM	2+1	Welded	5	270	67,5
AMg6M + AMgM	2+1	Glue-welded	5	400	
AMg6M + AMgP	2+1	Welded	5	280	68,2
AMg6M + AMgP	2+1	Glue-welded	5	410	
AMg6M + AMgP	2+1,5	Welded	6	490	63,5
AMg6M + AMgP	2+1,5	Glue-welded	6	770	

*Overlap 25 x 25 mm

Table 70. Shear strength of glue-welded joints of alloy D16T after drilling of welded point (overlap 25 × 25 mm).

Glue	Combination of thickness in mm	Diameter of hole in mm	Breaking load in kg
FL 4S	1,2+1,2	6	315
MPF 1	1,2+1,2	6	289
VK 1	1,2+1,2	6	518
KLN 1 (Strengthened without heating)*	1,2+1,2	7	524
KLN 1 (Strengthened with heating)*	1,2+1,2	7	1113
VK 1	1,2+1,2	7	510
VK 7	1,2+1,2	6	226
VK 7	1,5+1,5	9	268
VK 7	2+2	10	290

*According to Ye. L. Apartseva

Table 71. Shear breaking load in kg of connections of Duralumin D16T depending on temperature (glue VK 7).

Joint	Temperature of test in °C					
	−60	20	150	230	250	275
Welded, 1.5 + 1.5 mm, diameter of nucleus 6.5 mm	—	510 / 450—652	518 / 487—567	522 / 450—577	489 / 450—532	430 / 416—457
Glue-welded, application of glue after welding, 1.5 + + 1.5 mm, diameter of nucleus 6.5	—	585 / 521—625	584 / 512—631	585 / 540—620	567 / 548—604	510 / 476—551
The same, diameter of drilled hole 9 mm	—	168 / 110—262	107 / 77—153	71	39 / 27—52	21
Welded, 2 + 2 mm, diameter of nucleus 7.5 mm	810	785	—	747	629	—
Glue-welded, application of glue after welding, 2 + 2 mm, diameter of nucleus 7.5 mm	1016	1066	—	788	746	—
Glue-welded, welding on glue 2 + 2 mm, diameter of nucleus 7.5 mm	740	745	—	679	713	—
Glue-welded with drilled point, 2 + 2 mm, diameter of hole 10 mm, welding on glue	230	290	—	272	200	—
The same, application of glue after welding	470	410	—	297	270	—

Investigating the properties of glue-welded joints, G. Henning [29] indicates that the increase in their strength is inversely proportional to the thickness of the elements; for a thickness of sheets over 4-5 mm strength is increased so insignificantly that the glue fulfills basically anticorrosive functions. In thin-sheet constructions the prevailing value is the additional strength of the glue layer. The author of work [29] considers that for a thickness of sheets up to 1 mm static tensile and fatigue strength of connections carried out by spot welding, gluing and glue-welding is in the ratio 1:2:3.

The glue layer to different degrees promotes an increase in strength of a welded joint. For given geometric parameters and material

of the connection the increase in its strength depends basically on strength and technological properties of the glue, and also on the technology of manufacture of the connection. As can be seen from Table 68, the biggest shear strength is possessed by glue-welded joints carried out with application of more elastic glues VK 1MS and VK 1, and least with application of glues K 153, EPTs 1 and KLN 1, which agrees with physical and mechanical properties of these glues (Chapter I).

For a given make of glue of higher strength is possessed by glue-welded joints carried out with introduction of glue in the cavity of the connection after welding by the capillary method. However this is not true for all cases. For example, glue-welded joints carried out with a layer if liquid glues VK 9, EPTs and K 153 and the method of introduction of glue after welding, possess practically identical shear strength. This is basically caused by the fact that the shown glues in the second case, due to bad penetrability, unstably fill the cavity of the connection.

Efficiency of welded and glue-welded joints at raised temperatures is practically identical (Table 71). Glue-welded joints carried out with glue VK 7 are more heat-resistant than in the case of introduction of glue into the cavity of a connection after welding. However these conclusions are tentative and require additional study.

Table 72 gives the mean value of breaking load during static shear multipoint (butt with rigid cover plate) welded, glue-welded and monotype rivited structural elements made from Duralumin D16T (Fig. 18). During manufacture of glue-welded elements glue KLN 1 is introduced in the cavity of the connection after welding, then held before tests for 10 days at usual temperature for full polymerization of the glue. From Table 18 it is clear that glue-welded elements exceed the strength of welded and riveted elements. Upon achievement of the load limit the samples ruptured basically due to shear of welded points or rivets.

Table 72. Breaking load in kg during shear of structural elements (sheet δ = 1 mm + profile δ = 2 mm). According to N. I. Lopatin (Fig. 18).

Diameter of nucleus of point of rivet in mm	Joint		
	Welded	Glue-welded	Riveted
5,45	3180	3910	—
4	—	—	3120
3,5	—	—	1840

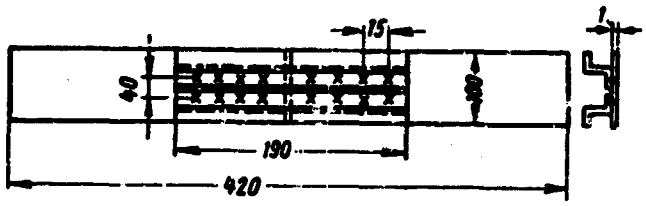


Fig. 18. Structural elements for test for static shear and vibration (D16T, 1 + 2 mm).

Breaking Strength

During determination of breaking efficiency of welded and specially glue-welded point connections, of very significant value is the type of sample and methods of tests [10]. Recently conducted additional investigations of breaking efficiency of glue-welded joints, carried out with application of new glues, have completely confirmed this. In spite of the considerable strength of the glue layer and independently of its nature, breaking strength of glue-welded joints turns out to be in a number of cases insignificantly higher than strength of a usual point. This is not caused by the fact that the presence of a glue layer in a welded point connection cannot in general promote an increase of its breaking strength during work, but design features of samples used for the shown tests.

Table 73 gives the mean value of breaking load obtained as a result of comparative tests of usual cross-like welded and glue-welded (with glue EPTs 1) samples made from aluminum alloys. Strength of glue-welded joints in this case insignificantly exceeds (on 8-10%) the strength of monotype usual point connections. The insignificant rigidity of a cross-like sheet sample leads to a clearly expressed work of glue layer on nonuniform breaking and tearing (Fig. 19b), the glue and welded point do not work simultaneously, and this consistently considerably lowers the efficiency of welded joints on breaking. During removal of the shown phenomenon the efficiency of a welded point on breaking is noticeably increased.

Table 73. Static breaking strength of cross-like samples.

Welded alloys	Combination of thicknesses in mm	Diameter of nucleus of point in mm	Breaking load in kg		Ratio of breaking strength of welded to that of glue-welded joints in %
			Welded	Glue-welded	
AMg6M + AMgM	2+1	5	100	110	91
AMg6M + AMgP	2+1	5	115	125	92
AMg6M + AMgP	2+1,5	6	220	240	91,2

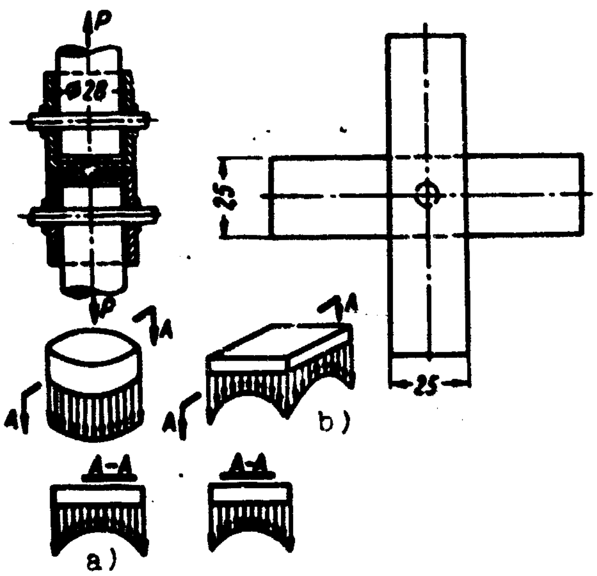


Fig. 19. Welded samples for breaking tests: a) special; b) usual cross-like.

Table 74 gives the mean value of breaking load obtained as a result of comparative tests for breaking of special single-point welded, glue-welded (with different glues) and monotype riveted samples from alloy D16T, in which work of the welded point flows under conditions close to uniform breaking, as this frequently takes place in real constructions. The given sample (Fig. 19a) consists of two point (rigid) cylindrical glasses connected by a welded point in combination with glue or only a welded point, or a rivet. Efficiency of glue-welded joints in this case turned out to be noticeably higher than usual ones welded in such conditions. The best strength is possessed, just as during shear, by glue-welded joints carried out with application of more elastic glues VK 1MS and KLN 1. Efficiency of riveted connections is noticeably lower than welded ones and especially glue-welded joints.

Table 74. Breaking load in kg of single-point samples (2 + 2 mm) during static breaking (Fig. 19).

Joint				
Riveted*	Welded**	Glue-welded** with application of glues		
		FL 4S	VK 1MS	KLN 1
360	410	500	820	790

*Diameter of rivet 5 mm.
**Diameter of nucleus of point 7 mm.

Strength During Twisting

To establish the real tensile efficiency of welded point and glued layers during static shear by tests of welded and glue-welded point connections in most cases is impossible, since destruction of them occurs in many cases from the excavated nucleus of the point, i.e., joint action of bending and breaking loads. As experiments show,

in a number of cases it is more rational to determine the efficiency of a welded point during shear by twisting tests of the shown connections. This permits one most fully and reliably to reveal the strength and especially plastic characteristics of cast metal of the nucleus of a point and the glue layer.

Table 75 gives data of shear tests by twisting of monopoint cross-like welded and glue-welded (welding by glue FL 4S) samples made from Duralumin D16T and magnesium alloy MA8. Samples were tested in a special attachment (Fig. 20). Conditions of tests were recorded on the diagram, giving a graphic dependence of torque or twist angle. By this diagram the angle corresponding to the greatest plastic deformation of cast metal of the nucleus of the point was determined.

Table 75. Results of mechanical shear tests by twisting of point connections.

Form of connection and material	Average torque in kgm	Twist angle in deg
Welded, D16T, 3 + 3 mm, diameter of nucleus 10 mm	4,8	3,7
Glue-welded, D16T, 3 + 3 mm, diameter of nucleus 9.9 mm	6,3	4,1
Welded, MA8, 3 + 3 mm, diameter of nucleus 10.5 mm	2,8	3,3
Welded, D16T, 2 + 2 mm, diameter of nucleus 8 mm	3,6	3,2
Welded, MA8, 7 + 7 mm, diameter of nucleus 15.5 mm	5,9	3,2

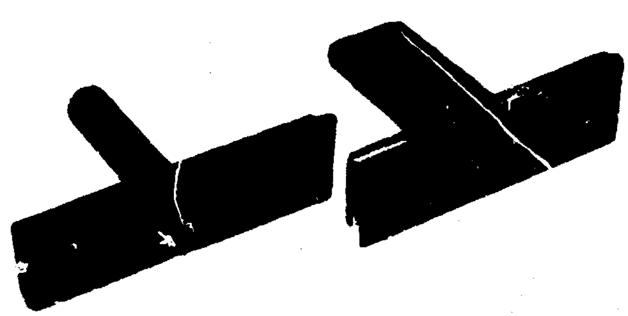


Fig. 20. Grips for twisting tests of welded point (together with broken sample).

The value of torque and twist angle depend basically on dimensions of the nucleus of the point and properties of the welded material. Values of these parameters for a glue-welded joint are higher than for welded ones, which testifies to the favorable influence of the glue layer on resistance to twisting and plasticity of the welded joint. Point connections made from alloy D16T are more plastic than those made from alloy MA8. For cast metal of the nucleus of the point of alloy D16T maximum shear stress 10.8, and for alloy MA8, 9.2 kg/mm^2. The biggest shear resistance (24 kg/mm^2) is at the nucleus of the point for glue-welded joints. This is caused by the fact that the glue layer, absorbing a large part of the stress, unloads the welded point. Shear stress is calculated by the formula

$$\tau_{max} = \frac{12M_{\kappa p}}{\pi d^3},$$

where $M_{\kappa p}$ – maximum torque during destruction of welded point, determined by the diagram, in kgm; d – diameter of nucleus of welded point in mm.

This formula considers stages of elastic and plastic deformation. By the described method it is possible to twist test welded and glue-welded joints only when thickness of sheets is 1.5 mm and more, possessing sufficient rigidity. Application for these tests of glue-welded cross-like thin-sheet samples should be avoided since real shear efficiency of welded point in the glue-welded joint is not reflected. Insignificant rigidity of the thin-sheet sample leads to clearly expressed working of the glue layer on nonuniform breaking (tearing); the glue and welded point work not simultaneously but consecutively.

For torsion tests of glue-welded joints with thickress of sheets less than 1.5 mm more rigid samples of new constructions were developed[1] consisting of two rings 1 (Fig. 21a) welded on the circumference at several points 4, or from two disks (Fig. 21b) welded in the center

[1]Sample developed by A. A. Itskovich. Author's certificate No. 164692.

at one point. After welding the samples are glued by epoxy-cement glue to steel flanges 2. The solid bonding of samples with flanges excludes any loss of stability of plates and ensures clean shear stresses. In avoidance of friction between elements of samples they are prepared in the form of rings with an external diameter of 100-120 mm and internal 60-80 mm. During welding of annular samples it is possible to modify the step of welded points, which is important for determination of strength of glue-welded joints fulfilled by a layer of liquid glue. For four welded points the step is 63 mm; for six, 42 mm; and for eight, 31.5 mm. Disk samples have a diameter of 40-50 mm. Dimensions of samples should be selected so that strength of their glue connection with flanges exceeds the shear strength of the welded points.

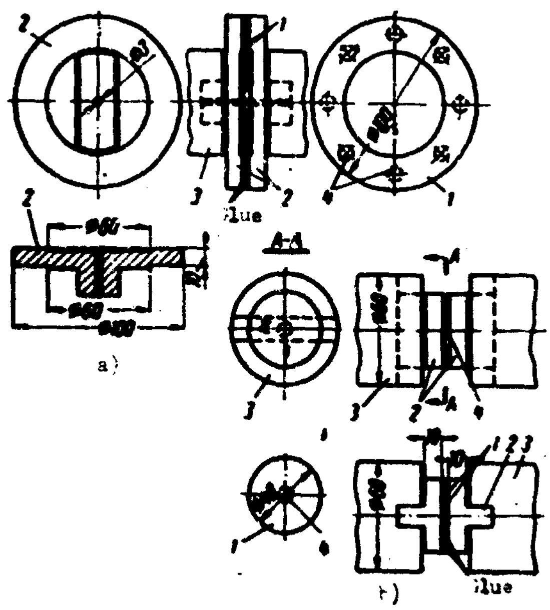


Fig. 21. Diagram of arrangement for shear test of welded point connections by torsion: a) for annular samples; b) for disk samples.

During tests the sample with flanges is secured in special clips 3, having in ends grooves for flanges. The clips are placed in holders of the testing machine. Destruction occurs in the plane of division of welded samples. Rupture stress in welded points is calculated by the formulas:

1) for annular samples

$$\tau = \frac{M}{\frac{d+d_0}{4} n \frac{\pi d_m^2}{4}} \text{ kg/cm}^2,$$

where M — torque in kgcm, determined on the machine; d and d_0 — external and internal diameters of the sample in cm; d_m — diameter of welded points; n — quantity of welded points;

2) for disk samples

$$\tau = \frac{M}{\frac{\pi d^3}{16}} \text{ kg/cm}^2,$$

where d — diameter of disk in cm.

The influence of the step of welded points on strength of glue-welded joints carried out with application of glues EPTs and KS 609 was studied (Table 76 and Fig. 22). It was established that the optimum is a step of 75 mm. With such a distance between points for glues KS 609 and EPTs shear stress is 3-4 times more than rated values. To increase strength and adhesional characteristics of the glue connection of flanges with samples (so that destruction during tests is on the glue-welded joint of the actual sample) the flange and sample should be prepared from one and the same material. The difference in strength of a glue-welded joint and glue (for highly durable glues) is attained also by the presence of a considerable difference in thickness of the glue layer. Strength of a glue connection decreases with an increase of thickness of the layer. In glue-welded connection of a sample the thickness of the layer is usually 0.24-0.28 mm, and thickness of the layer between flange and sample, polymerized in a compressed state, is equal to 0.07-0.09 mm.

Table 76. Shear strength in kg/cm^2 in process of twisting of glue-welded joints of alloy АМг6М depending upon step of welded points.

Combination of thicknesses in mm	Step of welded points in mm		
	30	60	90
Glue KS 609			
1+1	34.5	16	11
1.5+1.5	54	24	20
2+2	69	51	27
Glue EPTs			
1+1	60	33	18
1.5+1.5	96	51	37
2+2	108	69	51

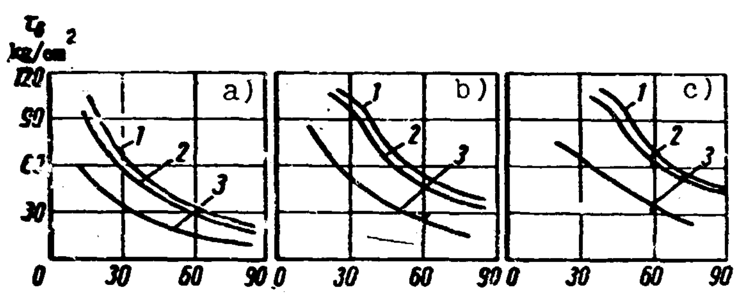


Fig. 22. Change of strength of welded and glue-welded joints depending upon step (in mm) between points during torsion test: a) 1 + 1 mm; b) 1.5 + + 1.5 mm; c) 2 + 2 mm; 1 – glue-welded joint, glue KS 609; 2 – the same, glue EPTs; 3 – welded joint.

For establishing the efficiency of the metal of the nucleus of separate welded points disk samples were tested, allowing one to obtain clean shear stress of separate welded points. Destruction during twisting of welded point occurs on that surface whose section modulus is less. Depending upon thickness of sheets and the diameter of the nucleus of the point d_m it will be destroyed in the plane of

connection of sheets or on a cylindrical surface. If one designates the section modulus of round surface F_1 between sheets by W_1, and the section modulus of the cylindrical surface with diameter d_m and height δ through W_2, then

$$W_1 = \frac{\pi d_m^3}{16}; \quad W_2 = \frac{\pi d_m^2}{2}\delta;$$

hence

$$\frac{W_2}{W_1} = \frac{8\delta}{d_m}.$$

For ultimate shear strength .. the nucleus of the point τ_1 and the base metal τ_2 maximum torques will be equal to

$$M_1 = W_1\tau_1 = \frac{\pi d_m^3}{16}\tau_1;$$

$$M_2 = W_2\tau_2 = \frac{\pi d_m^2}{2}\tau_2\delta.$$

Destruction with tearing from the sheet will occur if $M_1 > M_2$, i.e., when $d_m > 8\delta\frac{\tau_2}{\tau_1}$. It follows from this that to obtain clean shear of the nucleus of a welded point in point sheets is difficult, since the ratio of diameter of the nucleus of the point to thickness of the sheet is considerably greater than during welding of thick sheets.

In the described annular samples glued to a flange, welded points are destroyed by shear even with thin sheets. This is caused by the fact that the glue layer connecting the flanges with the sample as a single unit thickens the sample and thereby prevents any loss of its stability.

Using disk samples, it is possible to investigate the surface of destruction of glue-welded joints. Internal defects of the nucleus of the point revealed during twisting are a good criterion of appraisal of quality of a glue-welded joint carried out by a layer of liquid glue.

Investigation of Tensile Stressed State of Welded Joint with Overlapping

When loading an overlapped connection by stretching forces, in it, besides basic stresses, there appear secondary stresses from bending of elements of the connection due to noncoaxiality of application of the stretching load and concentration of stresses (Fig. 23). Bending creates secondary stresses which can a few times exceed the nominal calculation. Therefore, investigation of bending stress presents great practical and theoretical interest.

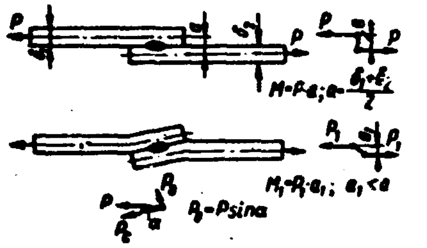


Fig. 23. Diagram of tensile load of samples.

Direct experimental determination of these stresses (which presents in this case the greatest interest) is practically impossible, since well-known methods of investigation of stresses in terms of deformations, with the help of the photooptical method, etc., do not permit separating from the found total stress the component of interest to us.

The necessary results can be given by indirect experimental investigations. In particular, bending stress can be determined according to the form of elastic line of loaded elements of a glue-welded joint deformed by bending moments. The form of the elastic line of bent elements of a connection is characterized by sags and angles of turn of sections.

The glue layer during loading by forces not causing plastic deformations in glued elements works as a single whole with the metal

[10]. In connection with this the assumption was made that in loading a glue-welded joint the whole section of the weld remains flat, only turning a certain angle, and for calculation width of the weld the value of overlap filled by glue was taken. It was assumed also that the increase in width of the weld elicits an increase in the radius of curvature of the turn of the section during deformation of the elastic line of the loaded connection and a proportional decrease in bending moment (bending stress).

During measurement of sags from longitudinal loads and radii of curvature of the elastic line of loaded elements of the sample to excluded any shift in the direction of sag of its elements. A majority of break testing machines have self-adjusting clamp heads and do not satisfy this requirement. An exception is the machine UM5, having rigidly secured head clamps with roller directrixes, preventing any shift of clamps in a transverse direction, which was used for the given experiments. Loading of samples was produced manually. Sags were measured with the help of pointer-indicating instruments of the 1-st class of accuracy with scale division values 0.01 mm, set on a special crosspiece, having the possibility to shift along the line of action of the load, and also by an optical method with the help of a tool microscope.

During measurements of sags of parts appearing due to the action of a longitudinal force, of very important value is the measuring force since it can introduce distortion to experimental data. Inasmuch as the measuring force of indicators used lies within limits of 100-250 g, then, according to the present work [7], it does not introduce noticeable distortions as a result of measurements.

Experiments were conducted on welded and glue-welded (with glue VK 1) samples made from alloy D16T (2 + 2 mm). Welding was produced on machine MTPT 600, glue was introduced after welding by the capillary method. Moreover, in correspondence with the above assumption, in glue-welded samples for width of the weld b the value of overlap was taken which in this case was 20 and 40 mm. In welded samples for width of the weld the diameter of the nucleus of the welded point was taken, on the average equal to 7 mm.

It is well known that additional bending stresses can appear during installation of an overlapped sample in clamps of the testing machine. This is especially perceptible in case of application of a machine with rigidly secured clamps. Stresses of installation bend can attain a considerable value and are analytically calculated by the formula

$$\sigma^{max}_{у.из.} = \frac{3E\delta^2}{4l^2} \; [7].$$

They turn out to be proportional to thickness δ of joined sheets and indirectly proportional to distance l from the connection to the stop (length of half of a sample). These stresses can be completely removed with the help of linings equal to the thickness of joined sheets welded or glued to the installation part of the sample.

Loads on a sample during measurement of sags, taking into account the possible accuracy of reading of indications on the scale of the testing machine, and also elasticity of the material and tentative stress concentration factors, was accepted to be 2 kg/mm^2, i.e., for the shown samples 120 kg. Measurements of sag were produced with the help of indicators after every load of the sample three times for the same position of the measurement tool on the sample. Simultaneously on analogous samples sag was measured with the help of the tool microscope. For this on the end surface of the sample a groove was marked on the edge of the weld and also 10, 20, 30, and 40 mm from the weld, a shift of which under load was measured by the measuring scale of the microscope. Results of measurements and rated value of sag are given in Table 77.

Sag was calculated by the formula [8]

$$y_1 = \frac{\frac{1}{2}(\delta_1 + \delta_2)}{\left(1 + \delta k_1 \operatorname{cth} k_1 l_1 + \frac{k_1 \operatorname{cth} k_1 l_1}{k_2 \operatorname{cth} k_2 l_2}\right) \operatorname{sh} k_1 l_1} \operatorname{sh}(k_1 l_1 - k_2 l_2). \qquad ([illegible])$$

where δ_1 and δ_2 – thickness of joined sheets (parts) in mm; b – value of overlap in mm; l_1 and l_2 – length of joined parts in mm; k_1 and k_2 – accordingly equal to $\sqrt{\frac{P}{E_1J_1}}$ and $\sqrt{\frac{P}{E_2J_2}}$; P – load per unit width of part; E – elastic modulus; J_1 and J_2 – moments of inertia of section of parts, equal to $\frac{1\delta_1^3}{12}$ and $\frac{1\delta_2^3}{12}$.

Table 77. Results of measurement of sags* of overlapped joints under a load.

Distance x from weld in mm	Welded joint b = 7 mm					
	Experimental sag in mm				Calculation sag in mm	
	measured by indicator		measured by optical method			
	f	$f-f_0$	f	$f-f_0$	f	$f-f_0$
0	0,07	—	0,09	—	0,094	—
10	0,21	0,14	0,22	0,13	0,254	0,16
20	0,31	0,24	0,35	0,26	0,366	0,272
30	0,43	0,36	0,41	0,32	0,43	0,336
40	0,39	0,32	0,42	0,33	0,45	0,366

*Mean values are given.

Table 77. (Cont'd).

Distance x from weld in mm	Glue-welded joint b = 20 mm					
	Experimental sag in mm				Calculation sag in mm	
	measured by indicator		measured by optical method			
	f	$f-f_0$	f	$f-f_0$	f	$f-f_0$
0	0,21	—	0,19	—	0,227	—
10	0,41	0,2	0,35	0,16	0,415	0,189
20	0,38	0,17	0,38	0,19	0,433	0,212
30	0,51	0,29	0,46	0,27	0,479	0,252
40	0,49	0,27	0,49	0,3	0,494	0,267

Table 77. (Cont'd).

Distance x from weld in mm	Glue-welded joint, b = 40 mm					
	Experimental sag in mm				Calculation sag in mm	
	measured by indicator		measured by optical method			
	f	$f-f_0$	f	$f-f_0$	f	$f-f_0$
0	0,35	—	0,38	—	0,37	—
10	0,46	0,11	0,47	0,09	0,463	0,093
20	0,57	0,12	0,52	0,14	0,518	0,148
30	0,4	0,14	0,54	0,16	0,536	0,166
40	0,55	0,2	0,54	0,16	0,539	0,169

In case of equality of thicknesses and lengths of halves of joints formula (1) is considerably simplified and when $k=\sqrt{\frac{P}{EJ}}$ it takes the form

$$y=\frac{\delta}{2}\cdot\frac{1}{1+\frac{b}{\delta}\sqrt{\frac{3\sigma_t}{E}}}\cdot e^{-x\frac{2}{\delta}\sqrt{\frac{3\sigma_t}{E}}}.$$

With the shown measurement scheme the value of sag for infinitely long parts

$$f=\frac{\delta}{2}-y.$$

In this case, for samples having a finite length

$$f=\frac{\delta}{2}-y-x\frac{\delta}{2l}.$$

where x - distance from edge of weld in mm.

Results of measurements and calculation data are graphically represented on Fig. 24, where the dot-dash curve shows the calculation form of the elastic line of loaded elements of the joint. For clarity

this graph shows values $f-f_0$, i.e., change of sag relative to the point corresponding to the beginning of the weld.

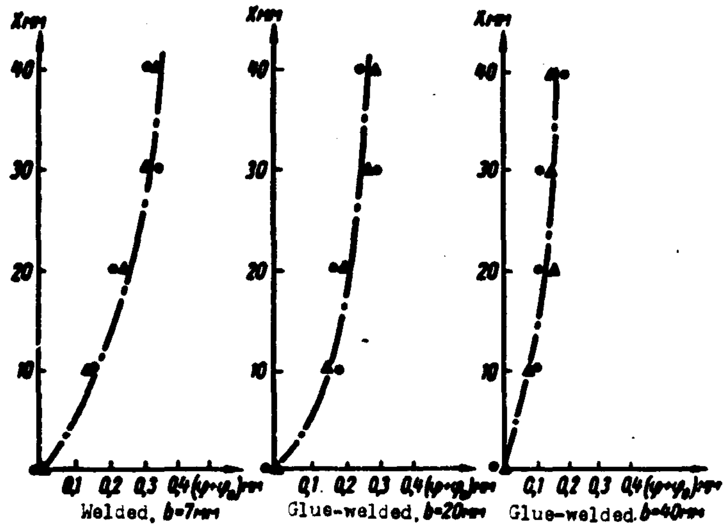


Fig. 24. Change of form of elastic line of loaded parts depending on width of weld: ▲ – measurement by optical method; ● – measurement by indicator deflectometer.

During investigation of glue-welded joints results of measurements and rated values of sag during use of the described methods of measurement coincide with the same accuracy as during tests of welded joints (average scattering of data 20-25%). Consequently, within limits of known elastic deformations the difference in values of elastic moduli of metal and glue does not render an essential influence on behavior of parts under load, and for loaded glue-welded joints calculation dependences obtained by B. B. Zolotarev [7] for roller and point welded joints can be used.

Elastic lines of loaded elements (Fig. 24) gave the possibility of graphically finding the radius of curvature ρ of the bent section of samples and calculating the change of values of bend with comparison of welded and glue-welded joints. For weld width b the bending moment per unit of sample can be defined by formulas (1) and (2):

$$M_{из} = \sigma_{из} W. \tag{1}$$

where

$$\sigma_{из} = \frac{3\sigma_л}{1 + \frac{b}{\delta}\sqrt{\frac{3\sigma_л}{E}}};$$

$$W = \frac{\delta^2 \cdot 1}{6};$$

after substitution and conversion we obtain

$$M_{из} = \sigma_л \frac{\delta^2}{2\left(1 + \frac{b}{\delta}\sqrt{\frac{3\sigma_л}{E}}\right)}.$$

$$\frac{1}{\rho} = \frac{M_{из}}{EJ}. \tag{2}$$

Putting in expressions (1) and (2) the data of tested samples, we obtain for welded samples (width b = 7 mm) $M_{изг_1}$ = 108 kgmm, for glue-welded with an overlap of 20 mm $M_{изг_2}$ = 93 kgmm, and for glue-welded with an overlap of 40 mm $M_{изг_3}$ = 76 kgmm. Thus, introduction of glue in the overlap of a welded joint leads to a 14% decrease of bending moment for an overlap of 20 mm and 30% with an increase of overlap to 40 mm (stress in the sheet $\sigma_л$ = 2 kg/mm^2).

In subsequent experiments samples were loaded until the appearance of cracks in the limb zone of overlap. Analytically determined was the change in bending stresses in different sections of welded and glue-welded joints under differing loads and diagrams of bending stress were constructed (Fig. 25). From Fig. 25 it is clear that the increase of effective width of the weld induced by introduction of glue in the overlap of a welded joint leads to a considerable decrease on the value of overlap and effective stress in the sheet).

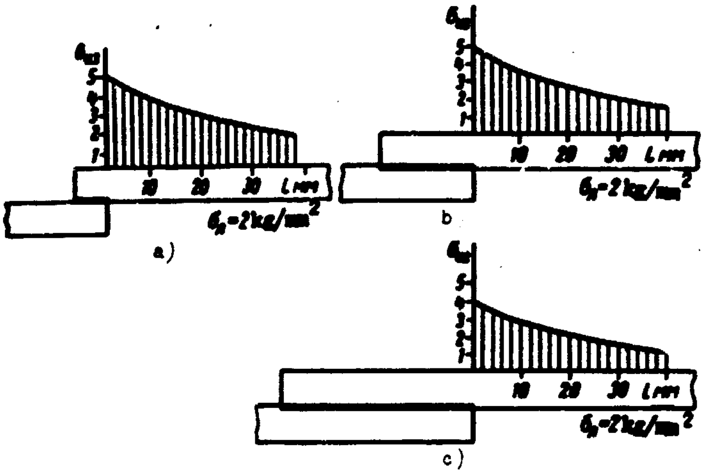


Fig. 25. Diagrams of bending stress during loading of overlapped connection of alloy D16T (2 + 2 mm) by a tensile force: a) welded joint, b = 7 mm; b) glue-welded joint, b = 20 mm; c) the same, b = 40 mm (glue VK 1).

Study of the dependence of radius of curvature of the elastic line of parts and bending stresses on applied load showed that with growth of stress in a sheet, bending stresses increase; however in glue-welded joints these stresses increase slowly and considerably less in absolute value (Fig. 26). With achievement of a certain critical value of tensions in a sheet, corresponding to the moment of destruction of the glue layer, bending stresses instantly increase to the level of those effective in the welded joint, but the elastic line of elements of the connection obtains the form corresponding to elements welded without glue (Fig. 26).

Determination of the zone of scattering of ultimate load corresponding to destruction of the glue layer showed that one can expect maximum efficiency of glue-welded joints during work of them under conditions when stresses in a sheet do not exceed 9-11 kg/mm^2 (i.e., in vibration loads, well confirmed by further investigations).

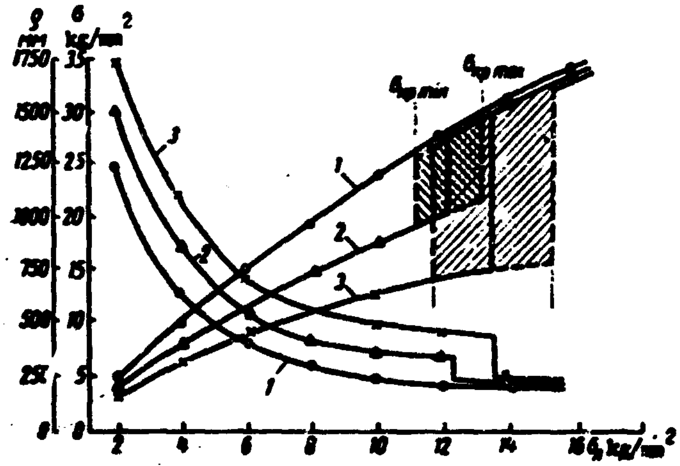


Fig. 26. Dependence of bending stresses and radius of curvature of the turn of a weld of overlapped connections on effective stresses in sheet: 1 — welded, b = 7 mm; 2 — glue-welded, b = 20 mm; 3 — the same, b = 40 mm.

Also analytically determined were breaking stresses in the weld zone under loads corresponding to the beginning of destruction of the glue layer. Breaking stress in an overlapped connection, loaded by a shearing force, can be defined by formula

$$\sigma_{\text{от}} = 2{,}3P'\left[\frac{1}{\delta_2}\cdot\frac{\operatorname{ch}2{,}3\left(\frac{b}{\delta_1}-\frac{y}{\delta_1}\right)}{\operatorname{sh}2{,}3\cdot\frac{b}{\delta_1}}+\frac{1}{\delta_2}\times\right.$$
$$\left.\times\frac{\operatorname{ch}2{,}3\frac{y}{\delta_2}}{\operatorname{sh}2{,}3\frac{b}{\delta_2}}-\frac{1}{2{,}3b}\right].$$

where P' = Pα (angle of rotation of weld α is defined by the method described in work [10]).

When $\delta_1 = \delta_2$, $E_1 = E_2$ and $l \to \infty$ the formula is simplified and takes the form

$$\sigma_{om} = 2{,}3P \cdot \frac{1}{\frac{b}{\delta} + \sqrt{\frac{E}{3\tau_A}}} \times$$

$$\times \left[\frac{1}{\delta} \cdot \frac{1 + \operatorname{ch} 2{,}3\left(\frac{b}{\delta} + \frac{y}{\delta}\right)}{\operatorname{sh} 2{,}3\frac{b}{\delta}} + \frac{1}{\delta} \cdot \frac{\operatorname{ch} 2{,}3\left(\frac{y}{\delta}\right)}{\operatorname{sh} 2{,}3\frac{b}{\delta}} - \frac{1}{2{,}3b} \right];$$

it is obvious that maximum breaking stresses act in boundary points of the overlap, i.e., y = b and y = 0. In this case the formula takes the form

$$\sigma_{om_{max}} = 2{,}3P \cdot \frac{1}{\frac{b}{\delta} + \sqrt{\frac{E}{3\tau_A}}} \times$$

$$\times \left[\frac{1}{\delta} \cdot \frac{1 + \operatorname{ch} 2{,}3\frac{b}{\delta}}{\operatorname{sh} 2{,}3 \cdot \frac{b}{\delta}} - \frac{1}{2{,}3} b \right].$$

Substituting values, we obtain: when b = 7 mm (welded joint) $\sigma_{om_{max}}$ = 1.38 kg/mm^2; when b = 20 mm (glue-welded joint) $\sigma_{om_{max}}$ = = 1.15 kg/mm^2; when b = 20 mm (glue-welded joint $\sigma_{om_{max}}$ = 6.81 kg/mm^2.

Minimum breaking stresses act in the middle of the seam (y = b/2). Calculated values are given in diagrams of breaking stress (Fig. 27). From Fig. 27 it is clear that together [illegible] the fall of absolute value of detaching stresses, distribution of them in a glue-welded joint becomes considerably more uniform then in a welded joint, which decreases their concentration 30-70% (depending upon overlap and effective stress in the sheet).

Calculated in terms of maximum tearing stress, the linear detaching load on the edge of overlap (66 kg for a connection with length of overlap 20 mm and width of sample 30 mm) turned out to be practically comparable with the characteristic of resistivity

of used glue (VK 1) to nonuniform breaking (20-22 kg/cm). This permits making a conclusion concerning the fact that, using glue possessing raised resistance to nonuniform breaking, it is possible to increase still more the efficiency of glue-welded joints.

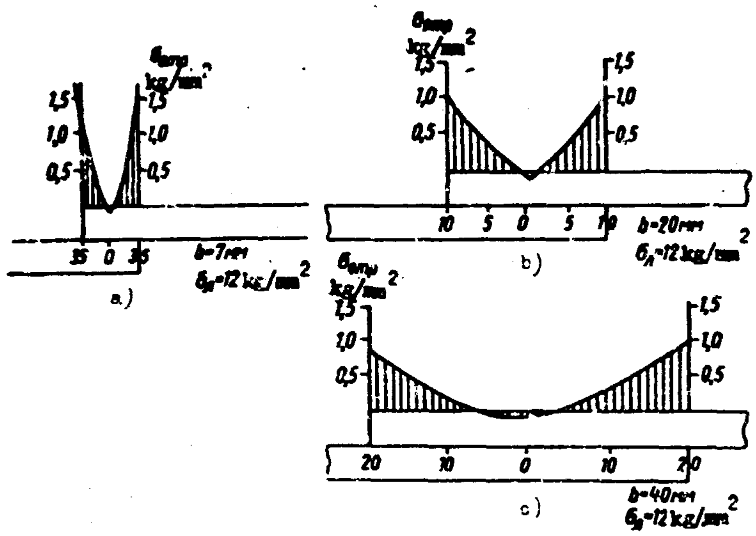


Fig. 27. Diagrams of cutting stress during load of overlapped connection D16T (2 + 2 mm) by tensile force: a) welded joint, b = 70 mm; b) glue-welded joint, b = 20 mm; c) the same, b = 40 mm (glue VK 1).

Fatigue Strength

The presence of a glue layer in a welded point connection especially noticea y increases its strength in vibration loads [10, 37, 39]. During load of a glue-welded joint by cyclical loads the glue layer absorbs a considerable part of stresses by unloading the welded point. Such redistribution of stress leads to a considerable lowering of their concentration in the zone of the welded point, which promotes an essential increase of fatigue strength of glue-welded joints.

According to work [10], fatigue strength of glue-welded joints exceeds the strength of all other forms of nondetachable connections.

Thus, for example, fatigue strength obtained during axial extension when $\frac{\sigma_u}{\sigma_0}$ = 0 welded of samples of steel St 38, carried out by overlapping was 4.5 kg/mm^2, when glue-welded 7 kg mm^2 and glued 6 kg/mm^2.

Analogous indices when $\frac{\sigma_u}{\sigma_0}$ = 0 are with 5.2; 7.2 and 6.4 kg/mm^2 [30].

Higher strength is attained during fatigue tests of structural elements on variable bending loads [39]. Thus, for example, fatigue strength of glued small I-beams turned out to be equal to 5 kg/mm^2 when welded by spot welding 9 kg/mm^2 and glue-welded 11 kg/mm^2. The comparatively low strength of glued elements is explained, obviously, by the strong influence of nonuniform breaking in the zone of maximum bend.

Experimentally it was established that efficiency of glue-welded joints in vibration loads, along with the structural form of joined elements, is very significantly influenced, just as during static loads, by the properties of glues used and technology of manufacutre of joints.

Figures 28-34 gives curves of fatigue strength of structurally similar welded and glue-welded one- and two-row connections of alloy D16T (sheet 1.5 mm) with overlapping (power), and also connections of both (power) of alloy D16T (sheet 2 mm) with rigid facing (made from channel iron) and alloy AMg6-1 (sheet 2 mm) with a bilateral flat cover plate carried out by glue welding and the capillary method with application of different glues. Comparative tests were conducted during axial extension by asymmetric cycle loading with cycle factor 0.1 on the basis of 10^7 cycles. As can be seen from Figs. 28, 30, and 32, fatigue strength (conditional) for glue-welded single-row connections is 1.5-2 times higher than for welded joints and is 3 kg/mm^2 for connections with glue KLN 1; about 4.5 kg/mm^2 with glue VK 1MS; 4.2 kg/mm^2 with glue VK 9; about 3.4 kg/mm^2 with glue KS 609 and 4.5 kg/mm^2 with glue VK 1. According to work [10], for analogous

glue-welded joints with glue FL 4S this value is equal to 4 kg/mm^2 and for glue connections 5 kg/mm^2. However, failure of glued connections occurs due to tangential stresses (in the layer of glue), therefore the curve of fatigue of glue connection, constructed according to normal stresses in the sheet, is purely conditional.

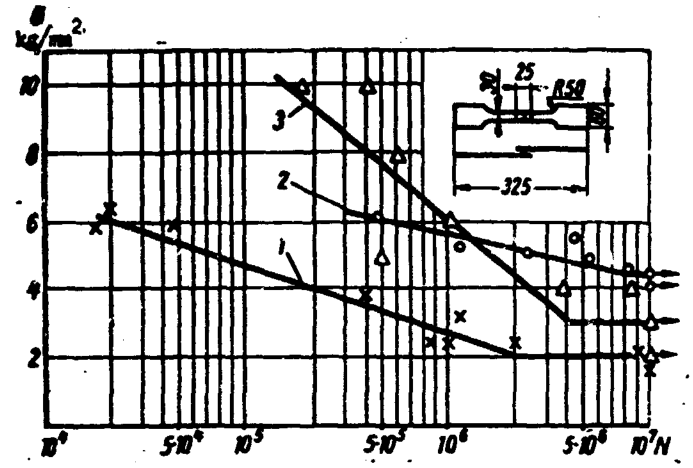


Fig. 28. Fatigue strength of single-row overlap connections of alloy D16T (1.5 + 1.5 mm): 1 – welded; 2 – glue-welded (glue VK 1SM); 3 – the same (glue KLN-1). Glue introduced after welding.

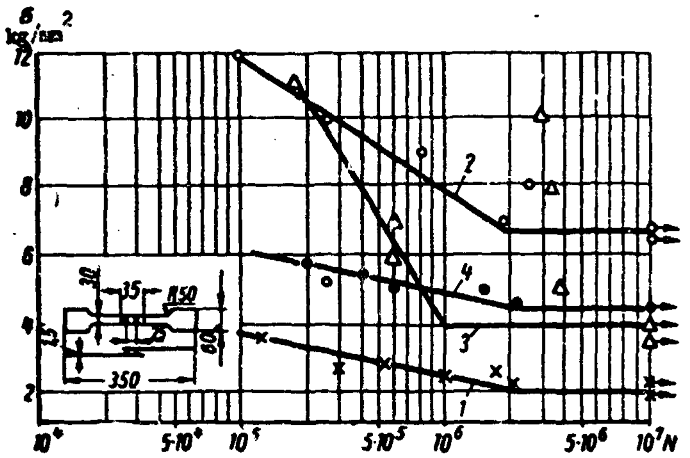


Fig. 29. Fatigue strength of two-row overlapped connections of alloy D16T (1.5 + 1.5 mm): 1 – welded; 2 – glue-welded (glue VK 1MS); 3 – the same (glue KLN 1); 4 – the same (glue FL 4S). Glue introduced after welding.

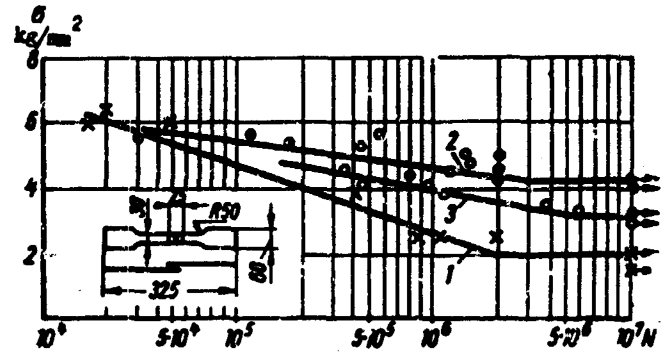


Fig. 30. Fatigue strength of single-row overlapped connections of alloy D16T (1.5 + 1.5 mm); welding on glue: 1 – welded; 2 -- glue-welded (glue VK 9); 3 – the same (glue VK 1SM).

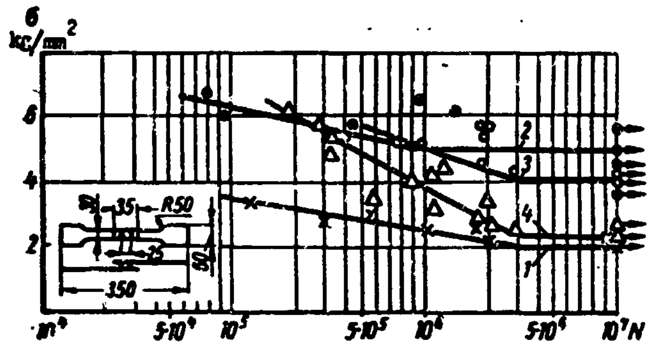


Fig. 31. Fatigue strength of two-row overlapped connections of alloy D16T (1.5 + 1.5 mm); welding on glue: 1 – welded; 2 – glue-welded (glue KLN 1); 3 – the same (glue VK 1MS); 4 – the same (glue VK 9).

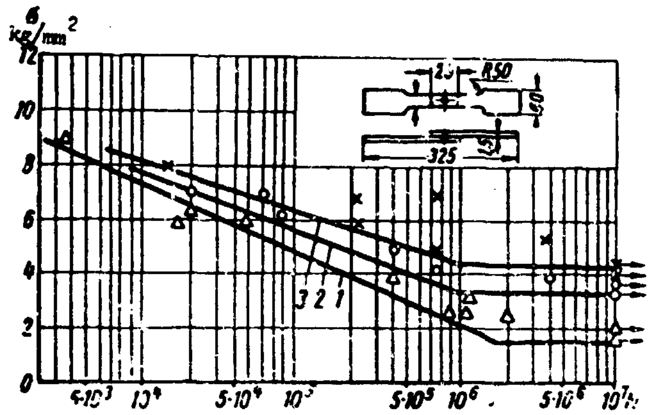


Fig. 32. Fatigue strength of single-row overlapped connections of alloy D16T (1.5 + 1.5 mm): 1 – welded; 2 – glue-welded (glue KS 609); 3 – the same (glue KS 1). Glue introduced after welding.

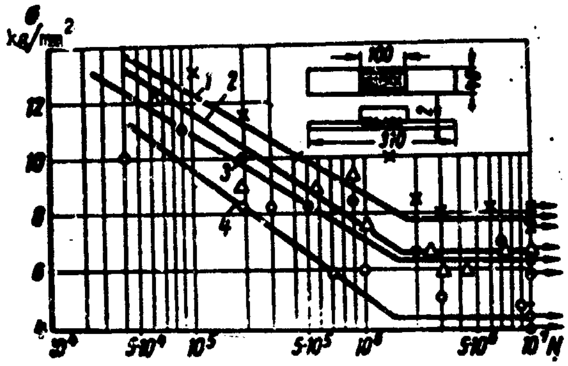


Fig. 33. Fatigue strength of two-row connections of alloy D16T (2 + 2 mm), butts with a rigid cover plate: 1 – welded; 2 – glue-welded (glue FL 4S); 3 – the same (glue KLN 1); 4 – the same (glue VK 1).

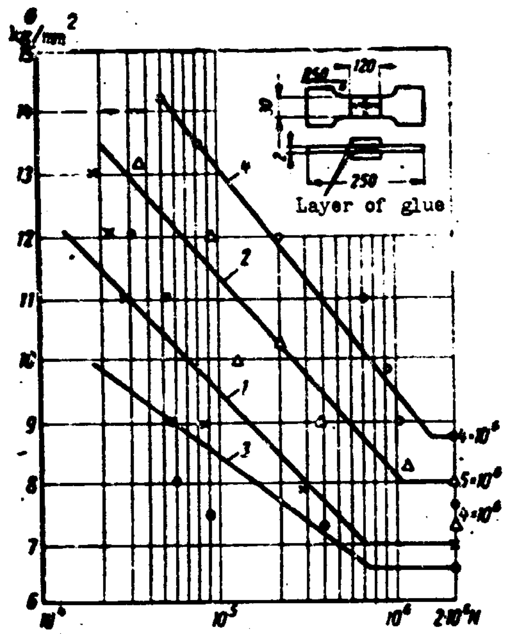


Fig. 34. Fatigue strength of two-row connections of alloy AMg6-1 (2 + 2 + 2 mm), butts with bilateral flat cover plate: 1 – welded; 2 – glue-welded (glue KS 609); 3 – riveted; 4 – glue glue KS 609) [3].

In spite of a considerable lowering of concentration of stresses at the border of the nucleus of the welded point, leading to a noticeable increase of fatigue strength of the glue-welded joint on account of redistribution of part of the load on the glue layer, failure of single-row overlapped glue-welded samples, similarly welded, occurs mainly near the point nucleus (Fig. 35). This apparently is caused by the fact that the behavior of the shown type of samples during vibration loads is decisively influenced by considerable bending stresses appearing in plates of the sample due to noncoaxiality of application of the tensile load. These stresses can somewhat exceed nominal calculation. Furthermore, in single-row glue-welded joint the weakened zone of the glued layer experiencing the most dangerous stress of nonuniform breaking spreads over almost all the area of overlap [10]. In separate cases destruction of single-row glue-welded samples, carried out with application of highly durable glues, occurs in a zone distant from the nucleus of the point (Fig. 35c).

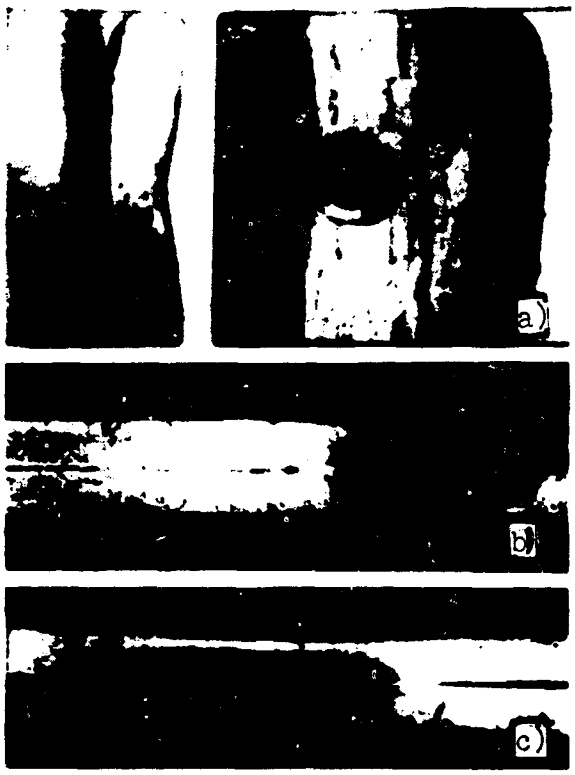


Fig. 35. Character of fatigue breakdown of glue-welded monopoint overlapped connection: a) external view; b) and c) macrostructure.

For a two-row overlapped seam fatigue-strength for glue-welded joints is 2-2.5 times higher than for welded, and is 4 kg/mm^2 for connections with glue KLN 1, about 6.7 kg/mm^2 with glue VK 1MS, 4.5 kg/mm^2 with glue FL 4S (Fig. 29) and about 5 kg/mm^2 with glue VK 9 (Fig. 31). In a similar welded joint with glue VK 1 this value is 6.5 kg/mm^2, for glue connection (glue VK 1) 6 kg/mm^2, for riveted about 2.5 kg/mm^2 [10].

A comparison of data on Figs. 28-31 indicates higher fatigue strength for single-row and two-row glue-welded joints carried out with introduction of glue after welding by the capillary method, additional indicating the advantages of the given method.

In contrast to usual overlapped joints, considerably greater efficiency during vibration loads is possessed by power connections on butts with rigid (channel iron) and bilateral flat cover plates. Thus, for example, welded joints have a fatigue strength of 4.2 kg/mm^2, glue-welded (glue VK 1) 7.9 kg/mm^2, glue-welded with glue KLN 1 6.6 kg/mm^2 (Fig. 33) and glue-welded with glue KS 609 8 kg/mm^2 (Fig. 34). A still greater increase of fatigue strength for a given type of welded joints is ensured by a glue layer of VK 1MS and VK 9, which agrees with physical and mechanical properties of these glues (Chapter I).

The higher fatigue strength for two-row glue-welded overlapped connections as compared to single-row is caused by the fact that thanks to redistribution of stress in the section of a glue-welded joint there is a shift in maximum concentrations of stress from the weaker, near-weld zone, weakened by the thermal influence of heating and, consequently, possessing higher efficiency. A confirmation of this is found by comparison of the character of fatigue breakdown of connections. Thus, two-row glue-welded overlapped connections, in contrast to single-row, are destroyed in the zone distant from the nucleus of the point (Fig. 36a). For a similar welded joint the characteristic destruction is at the border of the nucleus of the point (i.e., in the zone of maximum concentration of stress, Fig. 36b).

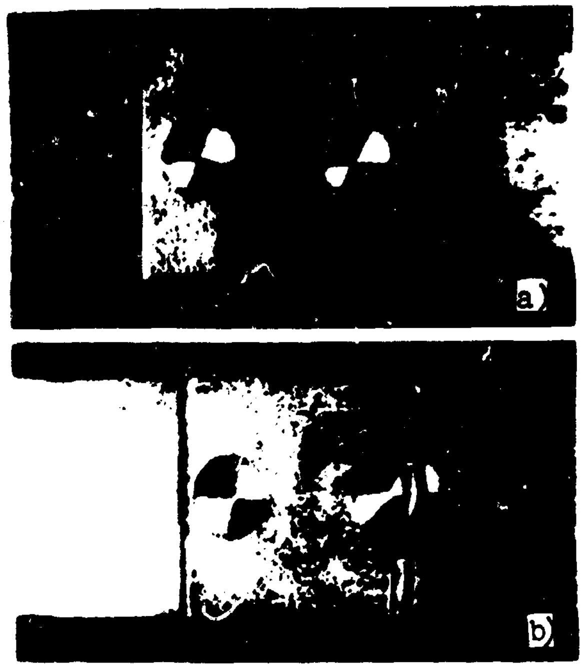


Fig. 36. Character of fatigue breakdown of two-row overlap joint: a) glue-welded; b) welded.

For a three-row overlapped weld fatigue strength for glue-welded joints is still higher than for two-row and is 7 kg/mm^2 for connections with glue VK 1 and 6.8 kg/mm^2 with glue VK 1MS, which is 3 times higher than for welded and riveted joints (Fig. 37).

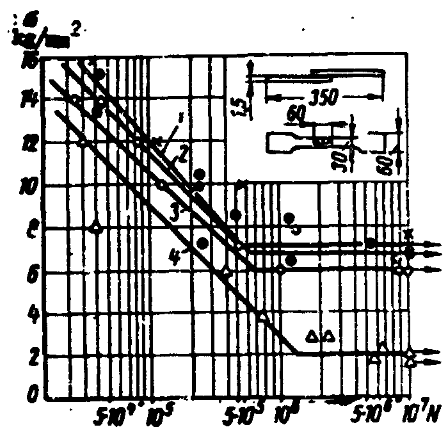


Fig. 37. Fatigue strength of three-row overlap connections of alloy D16T (1.5 + 1.5 mm): 1 – glue-welded (glue VK 1MS; 2 – the same (glue VK 1); 3 – glue (glue VK 1); 4 – welded.

However, further increase of fatigue strength of glue-welded flat overlapped connections by an increase in overlap is practically impossible to carry out. For a defined value of overlap the decisive influence on efficiency of a connection during vibration loads is only the geometric form of the section of the connection. For checking this assumption monolithic (milled) samples of overlapped connections cut from basic metal whose forms exactly repeated the section of a glue-welded joint were fatigue tested. Fatigue strength in this case attained 7 kg/mm^2 (Fig. 38). A comparison of obtained data on fatigue strength and the character of destruction of two- and three-row glue-welded joints and monolithic models shows that glue-welded joints with shown glues completely lose the possibility of overlap connection, and to obtain high values of fatigue limit with this construction of a connection is practically impossible.

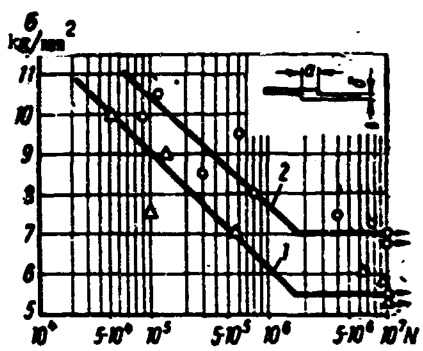


Fig. 38. Fatigue strength of models of overlap connections cut from base metal (D16T): 1) a = 20 mm, b = 2.5 mm; 2) a = = 35 mm, b = 1.5 mm.

Efficiency of welded and glue-welded joints with binding points during vibration loads is considerably higher than with working (power) points. This is caused by the fact that binding points and also the glue layer, in contrast to operating points, almost do not transmit noticeable forces between elements of the article which they connect. Due to this the work of such connections flows during vibration loads in more favorable conditions than connections with power points. Figures 39-41 gives curves of fatigue of welded and glue-welded joints of alloy D16T (sheets 0.8; 1.2 and 1.5 mm) with binding points carried out with a one-sided flat and rigid (from profile) cover plate with application of different brands of glues

and two technological variants. Comparative tests were conducted under axial extension by asymmetric cycling of the load with cycle factor 0.1 on the basis of 10^7 and $2 \cdot 10^6$ cycles.

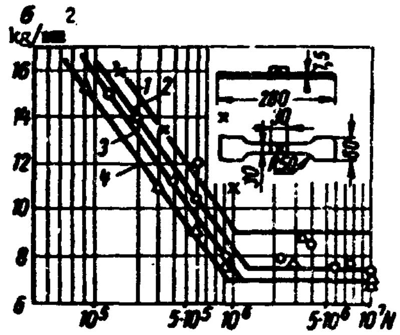


Fig. 39.

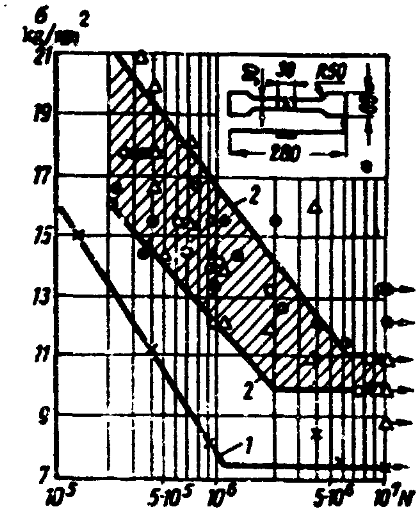


Fig. 40.

Fig. 39. Fatigue strength of connections made from D16T (1.5 + 1.5) with binding point; 1 - glue-welded (glue VK 1); 2 - glue VK 1); 3 - welded; 4 - riveted.

Fig. 40. Fatigue strength of connections made from D16T (1.5 + 1.5 mm) with binding point (flat cover plate: 1 - welded; region encompassed by curves 2-2 - glue-welded ▵ - glue KLN 1; ○, ● - glue VK 1MS; ◑ - glue VK 9.

Welded and riveted connections with a flat cover plate have almost identical fatigue strength, equal to about 7 kg/mm² (Fig. 39).

Glue-welded joints, independently of the make of glue used and type of connection, have considerably higher fatigue strength than welded and riveted. Thus, the fatigue limit of glue-welded monopoint connections of alloy D16T (1.5 + 1.5 mm) with a one-sided flat cover plate, carried out on glues VK 9, VK 1MS and KLN 1, independently of technology of their manufacture, is 10-11 kg/mm², on glue VK 1, 9 kg/mm² (Figs. 39 and 40).

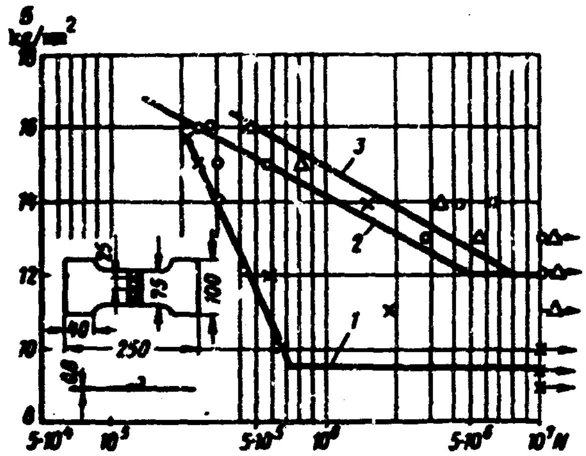


Fig. 41. Fatigue strength of connections made from D16T (0.8 + 1.5 mm) with binding points (rigid cover plate): 1 – welded; 2 and 3 – glue-welded (glues VK 1MS and FL 4S).

Connections with a binding point, having a rigid cover plate (simulating stringer set), possess considerably greater efficiency than connections with a flat cover plate. Thus, fatigue strength of welded joints is about 9.7 kg/mm^2, and glue-welded (with application of glues VK 1MS and FL 4S) 12 kg/mm^2 (Fig. 41).

The character of failure of glue-welded and welded joints also is sharply distinguished. Compensation of stress in the section of the cover plate in a glue-welded joint and the shift of maximum concentrations of stress from the zone of the welded point to the limb zone of the cover plate means that failure of these joints occurs, as a rule, on the edge of the cover plate (Fig. 42a). For welded joints characteristic failure is in the zone of thermal influence of the welded point (Fig. 42b).

Table 78 represents data of fatigue strength obtained as a result of comparative tests of welded, glue-welded (glue KLN 1 introduced after welding) and monotypical riveted structural elements made from alloy D16T during asymmetric axial extension with the frequency of repeated loads 200 cycles per minute on the basis of 10^6 cycles. The working load on all joints was changed within limits of 750-2000 kg. From Table 78 it is clear that fatigue strength of glue-welded structural elements is more than 2 times higher than strength of welded joints and 30% higher than riveted. During vibration loads

welded and glue-welded elements were destroyed, as a rule, through the profile of rigidity in the zone of middle welded points of the weld, but for riveted elements, in the sheet on the border of the extreme (external) row of rivets, i.e., the most weakened section.

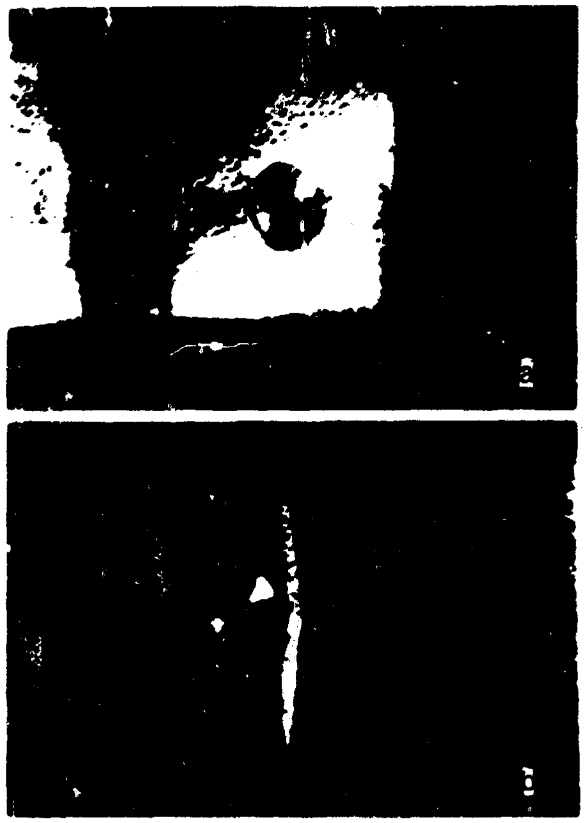


Fig. 42. Character of fatigue breakdown of connections with binding point: a) glue-welded; b) welded.

Table 78. Number of cycles before failure of structural elements made from alloy D16T (sheet δ = 1 mm + profile δ = 2 mm). According to N. I. Lopatin (Fig. 13).

Diameter of nucleus of point, rivet in mm	Joint		
	Welded	Glue-welded	Riveted
5,45	$47{,}6 \cdot 10^{3}$	$112 \cdot 10^{3}$	—
4	—	—	$88{,}8 \cdot 10^{3}$

Figure 43 represents curves of fatigue strength obtained as a result of comparative tests for repeated symmetric breaking of special rigid monopoint welded and glue-welded test pieces made from alloy D16T. The efficiency of glue-welded joints during repeated breaking is considerably higher than for welded. The especially great increase in efficiency of joints at these loads is ensured in case of application of new elastic glue KLN 1.

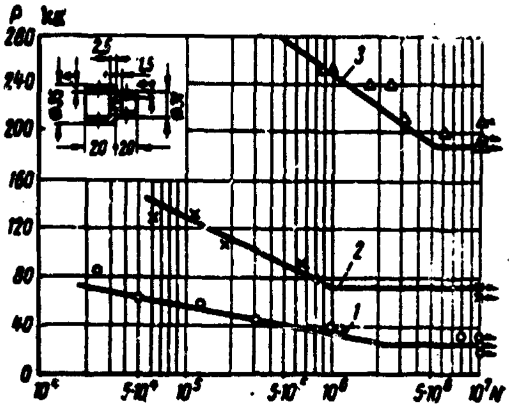


Fig. 43. Fatigue strength of joints made from alloy D16T during symmetric breaking: 1 - welded; 2 - glue-welded (glue FL 4S); 3 - the same (glue KLN).

It is well known that various kinds of concentrators of stress created by the form of joint or technological defects sharply lower fatigue strength of constructions. Application of high-strength steels in welded constructions, tested under fatigue loads does not have practical advantages over usual structural steel. Fatigue strength of welded joints made from aluminum alloys also depends very little on static strength of the basic metal.

Therefore technologists and designers the world over presistently look for causes of lowering of fatigue strength of different joints and means to increase it: they thoroughly select and improve the structural forms of elements of a construction, develop new electrodes, addition materials, search for strengthening methods of treatment of welded seams (rolling, forging, hardening, etc.).

Less well-known is the effect of the surrounding medium on fatigue strength. S. Benedichs [19] established that fatigue strength

of materials is essentially affected by different liquids (Table 79). As can be seen from Table 79, fatigue strength can be influenced to the positive as well as the negative side.

Table 79. Influence of different liquids on fatigue strength of materials.

Material	Medium	Change of fatigue limit in %
Steel with 13% Cr	Water	−40
Glass	"	−38
"	Ethyl alcohol	−23
"	Kerosene	+16
Carbon steel (0.75% C)	Water	−22
The same	Ethyl alcohol	−13
"	10% solution NaOH	+15
"	Gasoline	+18

G. Frankel, I. Bennet, and W. Holshouser [24] revealed that organic liquids (for example, hydrocarbons) essentially change the fatigue strength of aluminum alloys. The degree of change of strength is in defined dependence on length of the carbon chain in the molecule of hydrocarbon. Gases also possess an ability to affect fatigue strength of materials. N. Thompson [43] revealed for example that fatigue strength of carbon steel in an atmosphere of nitrogen is increased as compared to its strength in air. H. Gaugh and D. Sopwith [27] clarified that in a vacuum $1 \cdot 10^{-3}$mm Hg vibration strength of steel is increased 5%, copper 13%, brass 26%, etc., [27].

It is absolutely obvious that in most cases for the purpose of improvement of efficiency at fatigue loads, machine-building constructions should not be used in a medium of special liquids or gases. The thought arises about application of intermediate materials, variable surface conditions on the metal-environment border. Such material should have high adhesion to the metal, be plastic and not fail during

fatigue loads earlier than the basic material. Furthermore, the material should be sufficiently workable under conditions of production and alloy the simplest possible methods of application on the surface of metallic parts.

By numerous investigations conducted in the Central Institute of Welding of the German Democratic Repuolic under the leadership of Dr. W. Gilde it has been established that the enumerated requirements mostly correspond to glues used in industry for bluing metals [26, 28]. Experimental works used glues epiloks EGK 19, epiloks EKS 11, ZiS 217. The most frequently applied was glue of composition ZiS 217.

For clarification of the influence of glue coverings on fatigue strength of welded joints and elements of constructions numerous comparative experiments were conducted. Samples were tested for variable bend on a special installation (Fig. 44). The power exciter was an eccentric vibrator; the sample at zero points of oscillations was secured on springs. The variable for construction of the fatigue curve was amplitude of the oscillations changing the stress in the test pieces. Elements of welded constructions were tested on a 100-ton hydraulic pulser.

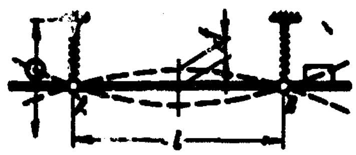


Fig. 44. Diagram of variable bend tests of test pieces.

Figure 45 gives results of tests, by the described method, of test pieces of steel MSt3 with artificial cuts to a depth of 1 mm. Thanks to application of glue coverings, during variable bend the strength of test pieces with cuts is increased almost 200%. Fatigue strength of a joint welded connection carried out by hand arc welding with cuts in the zone of the seam with a glue covering was increased

from 8 to 14 kg/mm^2. The same method was used to test steel samples with a strongly corroded surface. Depth of corrosion defeats attained 0.55 mm (average depth ∿0.25 mm). Applicator of a glue covering increased fatigue strength in this case from 9.5 to 15.5 kg/mm^2.

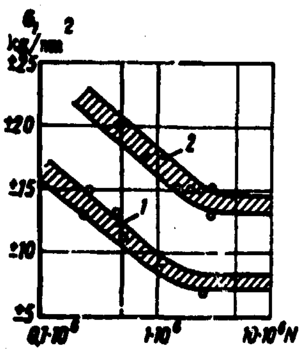


Fig. 45. Curves of fatigue strength of steel test pieces with a cut: 1 – test pieces without glue covering; 2 – test pieces with glue covering.

Besides samples, tests were also made of welded elements of constructions. Figure 46 shows the housing of the rear cross-bar of a truck. A similar welded construction sustains 1,350,000 cycles of changes of load when σ_{max} = +12 kg/mm^2 and σ_{min} = +3 kg/mm^2. After putting on the glue covering on welded joints such a construction did not fail at the same level of load in 2,600,000 cycles. Similar results are obtained during tests of welded automotive frames.

Fig. 46. Welding housing of rear truck cross-bar tested for fatigue.

The influence of glue coverings on fatigue strength of welded samples made from aluminum alloys was investigated. During the use of an alloy of type AlMg5 strength is also increased although to a smaller degree than for samples of steel (Table 80).

Table 80. Influence of glue coverings on fatigue strength of welded joints of steel and aluminum alloys.

Material and type of welded sample	Fatigue limit σ_{-1} in kg/mm²		Change of σ_{-1} with covering in %
	Untreated sample	Sample with glue covering	
MSt 3:			
corroded	±9.5	±15.5	+65
with joint weld	±8	±14	+75
with cuts	±3	±9	+200
AlMg 5:			
with joint weld	±3	±5	+65
with cuts	±3	±4	+30
with angular weld	±3	±4	+30

Investigations in the given direction continue for the purpose of accumulation of data which will alloy creation of a satisfactory theory of the influence of the surrounding medium on fatigue strength for production of glue compositions with optimum properties and technology of their application.

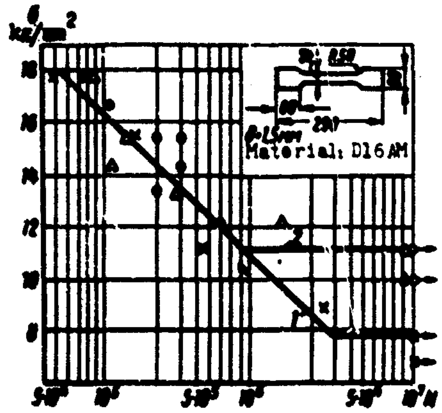


Fig. 47. Fatigue strength of flat samples made from alloy D16T (1.5 mm); 1 – without glue covering; 2 – with glue covering (glues KLN 1 and VK 9).

Figure 47 shows curves of fatigue strength obtained by authors as a result of comparative tests during axial extension with an asymmetric cycle of load of flat pieces made from basic metal (D16AM,

sheet 1.5 mm) and similar samples with a thin layer of glue KLN 1 or VK 9. As can be seen from Fig. 47, efficiency of the basic metal covering by a thin glue film is considerably higher than without a glue film, which agrees with data of foreign researchers as described above.

Investigation of Efficiency of a Glue Weld in Glue-Mechanical Joints

The glue layer in glue-mechanical joints promotes an increase of their strength. This depends on properties of glue used and also structural parameters of prepared connections. The investigations in particular show that efficiency of a glue seam in a glue-mechanical joint changes essentially during the change of the distance between power points. This is caused to a considerable measure by a change in specific pressures transmitted to the glue by power points: welded point to glue-welded or riveted to glue-riveted connections, etc. The value of these pressures depends, in turn, on the spacing of power points. During manufacture of glue-mechanical constructions it is necessary to know the optimum spacing of power points which ensures sufficiently high efficiency of the glue weld and, consequently, the quality of the joined connection.

The influence of pressures on efficiency of glue EPTs in joined connections depending on the distance between power points was studied initially on glue-welded, glue-rivetal and glue-screw standard samples made from alloy AMg6 of thickness 1 + 1; 1.5 and 2 + 2 mm, with two cover plates (Fig. 48) a power point spacing of 50, 75, and 100 mm, then on real three-ply structural elements 1500 × 300 × 50 mm consisting of aluminum sheathings of alloy AMtsAP of thickness 1-1.5 mm and plastic filler (Fig. 49).

The surface of the test pieces and elements of constructions for all shown joints was prepared by the work scheme used for spot welding chemical purification. Wide flat panels were preliminarily welded on glue on machine MTPT 400 and riveted on a hand pneumatic lever

press (Fig. 50). Glue-thread panels were prepared with self-threading screws with the help of a reversible pneumatic screwdriver RPO 350, having a head made from RPO 800. After polymerization of the glue the panels were cut by a milling cutter on separate samples to a width of 25 mm, welded points and rivets were drilled, screws unscrewed, and then the samples tested for static shear-cut. Structural elements were tested for transverse static bend according to the scheme for a single-span beam.

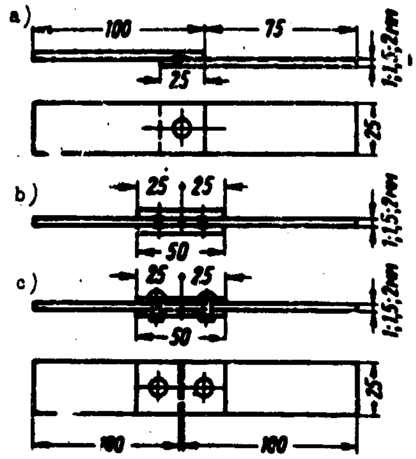


Fig. 48. Samples for static tests: a) and b) glue-welded; c) glue-riveted.

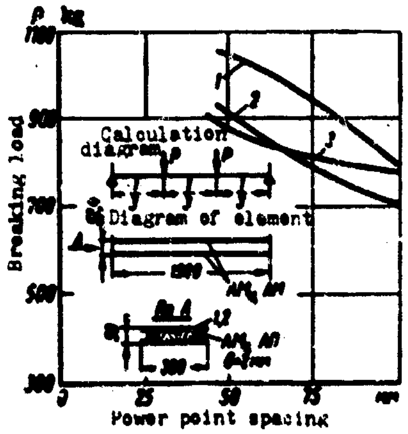


Fig. 49. Change of strength during transverse bend of three-ply structural elements depending on power point spacing: 1 - glue-welded; 2 - glue-riveted; 3 - glue-screwed.

Accepted type of symmetric samples is the most profitable for investigation of glue-rivet and glue-thread and less successful for glue-welded joints. In the process of spot welding on glue of a pack of three equal thicknesses thorough melting of the middle plate of the

sample occurs with formation of an increased point nucleus. This causes additional heating of parts worsened by deformation of plates between welded points and, as a result, lowering of pressure on the glue film. However a pack of three thicknesses in case of glue-rivet and glue-thread joints increases rigidity and lowers general deformation of sheets on account of a decrease in the action of spreading forces appearing during formation of the locking head of the rivet and plastic deformations of the metal in the process of cutting the thread.

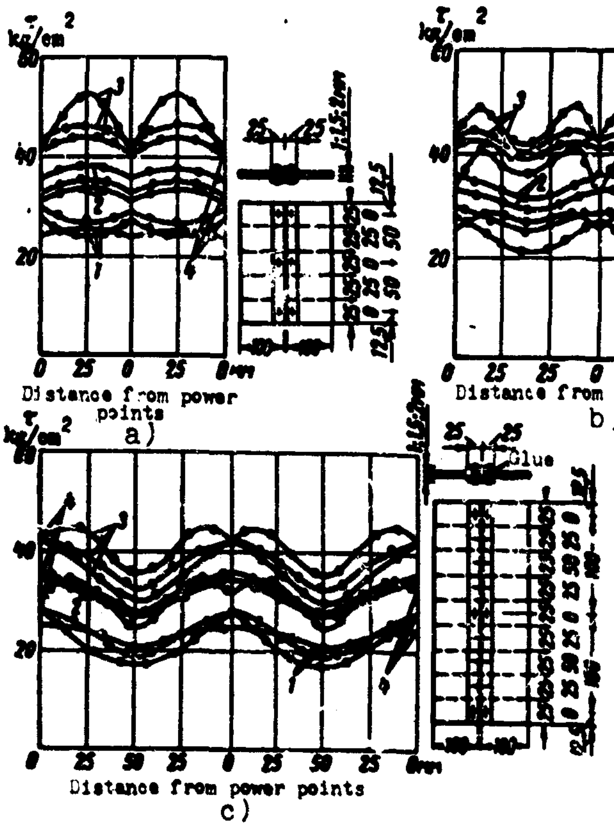


Fig. 50. Change of sheer stress of glue layer in glue-mechanical connections of alloy AMg6 depending on thickness of sheets in the pack and spacing of power points: a) 50 mm; b) 75 mm; c) 100 mm; 1 – 1 + 1 mm; 2 – 1.5 + 1.5 mm; 3 – 2 + 2 mm; 4 – samples with drilled power points (-●- are glue-welded; -●- are glue-screw; -◗- are glue-rivet).

Figure 50 shows the change in shear stress of the glue layer depending on spacing of power points in glue-welded, glue-rivet and

glue-screw samples. From Fig. 50a and b it is clear that failure shear stress of the glue layer in glue-welded joints is little changed with an increase of spacing from 50 to 75 mm. This is explained by the sufficient rigidity of the joint, ensuring proper specific pressure on the glue layer.

With an increase of the distance between welded points to 100 mm (Fig. 50c) a lowering of strength indices connected with deformation of sheets in the process of welding is observed, which involves lowering of specific pressure on the glue weld. Visual inspection of destroyed samples 1 mm thick revealed a lack of glue in separate places.

From Fig. 50c it is clear that strength of samples 2 mm thick considerably increases (1.7-2 times) as compared to samples 1 mm thick. This is explained by the fact that with an increase of thickness of samples the zone of pressure propagation from electrodes to the glue film is expanded. However, with a subsequent increase in the thickness of samples (more than 2-3 mm) the average thickness of the glue layer increases (due to temperature deformations of plates during welding) and its shear strength drops. This is caused to a considerable measure by the worsening adhesional properties of glue to metal, evidenced by failure on the metal-glue plane. Nonuniform thickness of the glue layer for a spacing of 100 mm and its influence on strength is confirmed by results of tests of samples cut at various distances from power points (Fig. 50c, curve 3). Analysis of data shown in Figs. 50a and b shows that stable strength of the glue layer is ensured in samples 1.5 mm thick. Specific strength of the glue layer of a glue-welded joint is less than a structurally similar glue joint; it cannot be calculated as a simple arithmetical sum of the strength of the welded point and glue layer on the remaining area of overlap [10]. The glue layer on ends of an overlap is weakened by the action of detaching forces manifested more considerably by glue-welded joints, which is worsened by the great thickness of the layer of glue in the given joints.

Comparing data of Fig. 50a-c, it may be concluded that static strength of glue layers in glue-rivet and glue-thread connections is 15-18% below the strength in a similar glue-welded joint, but strength of samples 2 mm thick with spacing of 100 mm and 1.5 mm thick in glue-welded joints for a spacing of 75 mm in both cases is approximately identical.

The greatest scattering of values of strength was revealed during tests of glue test pieces in glue-rivet and glue-screw joints with a spacing of 100 mm cut from the central part and for power points. This is explained by nonuniform pressure on the glue film. Local absence glue was noted in test pieces 1 mm thick with a spacing of 100 mm in glue-rivet connections and to a somewhat smaller degree in glue-thread joints. During formation of the locking head a rod of cold inserted rivet, ensuring transverse deformation, thoroughly fills the hole and causes a force N_p. After fitting the rivet the force transmitted from the glued pack to the rivet (through the annular surface of the rivet rod) decreases by a value of ΔN. From the condition of equilibrium it is possible to write the equation:

$$\frac{(N_p - \Delta N)\, l}{EF_3} = \varepsilon,$$

where N_p – force during formation of locking head; ΔN – change of force on sheet and glue; l – distance between rivets in cm; F_3 – area of longitudinal section of rivet in cm^2; ε – deformation of lengthening of glue and pack; E – elastic modulus in kg/cm^2.

After conversion of this formula we obtain

$$N_p - \varepsilon \frac{EF_3}{l} = \Delta N$$

or

$$\sigma_p - \varepsilon \frac{E}{l} = \Delta \sigma,$$

where σ_p — internal stress in glue-rivet connection; $\Delta\sigma$ — change of internal stress of glue-rivet connection.

In the process of fitting the second rivet $\Delta\sigma$ is increased until between sheets (accordingly between glue weld) a clearance is found, the difference $\sigma_p - \varepsilon\frac{N}{l}$ attains a maximum, and $\varepsilon = \varepsilon_{\text{кл}}$, where $\varepsilon_{\text{кл}}$ — deformation of glue weld.

Maximum value $\Delta\sigma = \sigma_{\text{н}}$; at the time of formation of the clearance equation

$$\sigma_p - \varepsilon\frac{E}{l} = \sigma_{\text{н}}$$

is valid.

A characteristic peculiarity of formation of glue-mechanical joints is that for them from the very beginning of setting of rivets, screws and so forth there immediately is observed a gradual increase in relative deformation. Besides, with setting of every subsequent power point (rivet, screw) the state of strain increases. Experiments showed that, for example, in glue-rivet joints carried out with epoxy glues the stress from thrust attains 200-300 kg/cm^2.

Investigation of the process of smoothing of a thread by self-cutting screws in glue-screw joints showed insignificant deformation of sheets (plastic packing of hole during cutting of thread), which noticeably drops with an increase of the thickness of test pieces. In glue-screw joints stress from spreading forces is 5-7% of the stress in glue-rivet joints during fulfillment with consolidated glue. During fulfillment of glue-screw joints by liquid glue, especially with application of thin sheets of annealed aluminum alloy (δ = 1 mm), with a screw spacing of 75 mm and more, the spreading forces of the thread considerably affect the character of change of stress. They depend on design features of conjugate sheet materials, the character of heat treatment of the aluminum alloy and technological factors (fitting of sheets, viscosity of glue compositions and others). Evidence of this is the absence of places not glued in test pieces 1.5 and 2 mm thick (spacing 100 mm) carried out from alloy AMg6.

Figure 50b gives curves of accretion of destructive shear stresses in glue weld for power point spacing 75 mm. From a consideration of these curves it follows that shear stresses of the glue layer between welded points, rivets, and screws, for test pieces 1.5 and 2 mm thick cut from the central part of a plate, coincide.

Analysis of results of tests of test pieces 1 mm thick with spacing of 75 mm showed that strength of the glue layer in a glue-welded joint is higher than in glue-rivet and glue-screw joints. Thus, for example, for spacing of 75 mm the strength of the glue layer in glue-welded joints turns out to be so considerable that it ensures a triple reserve of protection from shear forces appearing in three-ply constructions made from plastics and aluminum. A pack of three thicknesses for glue-rivet and glue-screw joints possesses sufficient rigidity (greater than a pack with glue-welded joints). This was confirmed by experiments on test pieces of small thickness (1 mm).

Investigation of the strength of glue layers on test pieces with rivets (position 4, Fig. _ b) was conducted after drilling for rivets. A study of destroyed samples showed that during formation of the locking head, by the force of pressing glue around the rod of the rivet it is pressed, forming a ring free from glue. Diameter of the ring corresponds to 2.5-3 diameters of the hole under the rivet. Specific shear strength of the glue layer after subtracting the area of holes and the zone free from glue is

$$\tau = \frac{P}{F_{кл}},$$

where P — breaking load on glue weld in kg; $F_{кл}$ — area of overlap after subtracting holes and zone free from glue in cm^2:

$$F_{кл} = F_{общ} - F_{отв} = 2\,(2{,}5\cdot 2{,}5) - \frac{2\pi\,(2{,}5d_{отв})^2}{4} =$$

$$= 12{,}5 - \frac{2\cdot 3{,}14\,(2{,}5\cdot 0{,}4)^2}{4} = 10{,}94 \quad cm^2;$$

$$\tau = \frac{P}{F_{кл}} = \frac{345}{10{,}94} = 31{,}4 \text{ kg/cm}^2.$$

From a comparison of the obtained results with data of tests represented on Fig. 50b, it follows that the difference in strength of the glue layer in glue-rivet joints lower than the strength of the glue layer in the interval between rivets is 10-15%.

Lowering of values of specific strength of a glue layer is caused by the fact that in the process of riveting the pressed glue will form a glue layer of nonuniform thickness increased according to distance from the hole. The presence of the hole leads to the appearance of an elastic stressed strip, to an increase in stress during loading of the joint. The glue layer promotes a more equal distribution of stress on the section (for example, during riveting on consolidated glue).

In Table 81 and on Fig. 49 is shown the change in efficiency of glue-rivet, glue-screw and glue-welded three-ply structural elements depending on spacing of power points. From Table 81 and Fig. 49 it is clear that during a change of spacing from 100 to 50 mm the ratio of experimental critical normal stresses in sheathing of the construction to their calculation value was increased for glue-screw joints from 2.25 to 3.5, and for glue-welded joints from 3.21 to 4.41. Shear stress here exceeded the stress appearing under a calculation load, for glue-welded joints with a spacing of 100 mm, in 2.12 times; for a spacing of 75-50 mm 2.32 times; for glue-rivet with spacing of 100 and 75 mm, 1.5 and 1.97 times; and for a spacing of 50 mm, 2.08 and 2.32 times; for glue-screw with spacing of 100 and 75 mm, 1.6-1.97 times; and for spacing of 50 mm, 2.02-2.22 times.

Strength of the glue layer strongly depends also on its thickness. Experimentally the influence of pressures from metallic bracings on the thickness of the glue layer depending on the spacing of power points was studied. The glue layer was measured by micrometer on test pieces after polymerization of the glue (Fig. 51). Analysis shows that optimum thickness of the glue layer in glue-weld, glue-rivet and glue-thread joints ensuring the required static strength is within limits of 0.1-0.25 mm.

Table 81. Strength during transverse bend of three-ply structural elements with glue-mechanical connections depending on spacing of power points.

Spacing of power points	Measured maximum breaking stresses in kg/cm² Normal $\sigma_{разр}$	Shear $\tau_{разр}$	$\frac{\sigma_{разр}}{\sigma_{расч}^{*}}$	$\frac{\tau_{разр}}{\tau_{расч}^{**}}$
Glue-rivet joints				
100	622	11,35	2,25	1,5
	714	13,1	2,65	1,71
	684	12,5	2,52	1,66
75	746	13,66	2,75	1,81
	674	12,35	2,5	1,63
	809	14,8	3	1,97
50	915	16,7	3,38	2,22
	950	17,4	3,5	2,32
	859	15,7	3,16	2,08
Glue-screw joints				
100	725	13,3	2,68	1,78
	690	12,7	2,56	1,7
	653	11,9	2,42	1,6
75	766	14	2,84	1,86
	809	14,8	3	1,97
	746	13,65	2,75	1,87
50	859	15,7	3,17	2,08
	915	16,65	3,38	2,22
	828	15,20	3,06	2,02
Glue-welded joint				
100	868	15,9	3,21	2,12
	828	15,4	3,06	2,06
	859	15,7	3,17	2,08
75	950	17,4	3,51	2,32
	995	18,2	3,69	2,43
	1037	17,95	3,83	2,51
50	1050	19,15	3,9	2,55
	1095	19,3	4,41	2,58
	1113	20,7	4,11	2,77

* $\sigma_{расч} = 230$ kg/cm²
** $\tau_{расч} = 7,5$ kg/cm²

A sufficiently equal distribution of thickness of the glue layer is observed for samples 2 mm thick. Static shear strength of glue weld is 40-55 kg/cm² for glue-welded, 36-48 kg/cm² for glue-screw and 33-45 kg/cm² for glue-rivet joints. As one should have been led to expect, a decrease in the spacing between power points led to a lowering of thickness of the glue film and equal distribution of it on mating surfaces, especially during connection of test pieces of small thickness.

Strength of glue-welded test pieces 1 mm thick for a spacing of 75 mm is somewhat higher than analogous test pieces with a spacing of 50 mm. Thickness of the glue film for a spacing of 75 mm for samples 1 mm thick is in the range of 0.12-0.22 mm, for a spacing of 50 mm in the range 0.18-0.30 mm. The reason for this phenomenon, probably, consists in shunting of the current causing additional

heating of the metal, in consequence of which in the surface layer there appear tensile stresses weakening the transmission of pressures. Therefore for glue-welded joints of alloy AMg6 1 mm thick the optimum spacing is 75 mm.

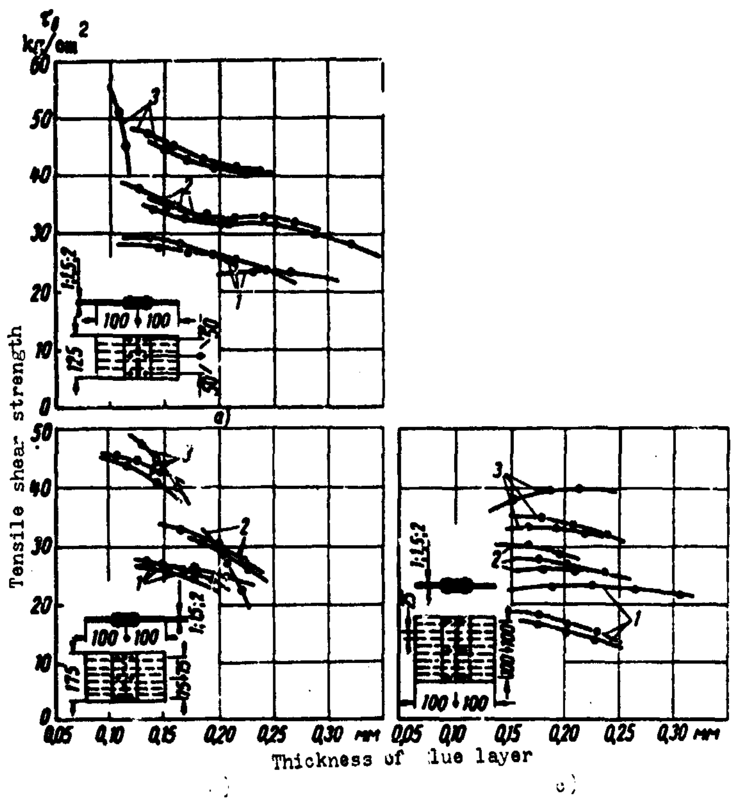


Fig. 51. Change of strength of glue weld in glue-mechanical joints depending on thickness of glue layer and spacing of power points: a) 50 mm; b) 75 mm; c) 100 mm; 1) 1 + 1 mm; 2) 1.5 + 1.5 mm; 3) 2 + 2 mm (-○- glue-welded; -●- glue-screw; -◑- glue-rivet).

Analysis of results of tests of glue-screw and glue-rivet samples of small thicknesses showed that for a pack of three equal thicknesses it is possible to increase the spacing between rivets and screws to 60-75 mm; rigidity of the pack ensures the necessary pressure on the glue seam, forming glue films with a thickness within limits of 0.14-0.23 mm for destruction shear force of 21-27 kg/cm^2. Experimental

analytical investigation of strength characteristics of destroyed samples permitted establishing that a certain thickening of the glue layer insignificantly affects the static strength of a glue joint.

Thus, given data show that shear strength of a glue layer strongly depends on rigidity of the pack. With a decrease of rigidity the strength characteristics drop noticeably. This conclusion was confirmed by subsequent experiments with the use, for glue-welded test pieces, of aluminum alloy AMgM. Test results are given in Table 82. From Table 82 and Fig. 51 it follows that destructive shear stress of the glue layer in glue-welded test pieces of alloy AMgM is 10-13% below that for analogous test pieces of alloy AMg6.

Table 82. Tensile shear strength τ_B in kg/cm^2 of glue layer depending on spacing of welded points and thickness of sheets of alloy AMgM.

Spacing of points in mm	Thickness of sheets in mm		
	1	1,5	2
100	18	25	36
75	21	26	39,5
50	23	27,6	39

Experiments showed that with an increase in thickness of test pieces from 2 to 4 mm the clearance between welded sheets is increased approximately 50%. This is caused by nonuniform heating and cooling in the thickness of the sheet and considerable plastic deformations as a result of pressing of parts in the process of welding. Accordingly the glue film during welding of thin sheets (to 2 mm) is considerably thinner than during welding of thick sheets and gives great rigidity and strength to the glue-welded joint. This additionally indicates the expediency of use of contact spot welding on glue in production of thin-sheet constructions.

Thus, on the basis of conducted investigations the following conclusions can be made.

1. The optimum spacing for glue-welded joints (welding on cold-consolidated glue) in three-ply constructions made from plastics with aluminum sheathings of alloy AMg6 1-1.5 mm thick, working under static loads, is 75 mm. Tensile shear strength of the glue spacing has a triple reserve as compared to calculation data.

2. The optimum spacing for glue-rivet connections for thickness of parts 1-1.5 mm is 50 mm. The shown spacing ensures sufficient pressure on the glue film and strength of the glue-mechanical connection with necessary reserve.

3. The optimum spacing for glue-stress connections for a thickness of parts 1-1.5 mm is 60 mm.

4. Maximum strength of glued seams in glue-welded, glue-rivet and glue-thread connections is attained with a thickness of glue film 0.1-0.25 mm.

Influence of Anticorrosive Coatings on Strength and Corrosion Resistance of Welded, Glue-Welded and Riveted Joints

In practice many riveted and welded constructions made from Duralumin are subjected to anticorrosive protection by methods of sulfuric acid, chrome anode oxidizing, parkerizing, etc. However during prolonged exploitation in different climatic conditions and considerable loads on oxidized surfaces of elements of these constructions in places with the most loaded (stretched) fibers there frequently appear so-called "gray hair" networks of small cracks of the anode film. These cracks in many cases are foci for corrosional defeats and subsequently develop into fatigue cracks which lower the efficiency of constructions under vibration loads. A number of source materials bear witness in particular to the essential lowering

of fatigue-strength of aluminum parts during application on their surface of anode film by the method of sulfuric acid oxidizing. In connection with this, at present anodized constructions without subsequent varnish and paint covering are not allowed prolonged exploitation.

As a result of replacement in a number of critical constructions of riveted glue-welded joints a still sharper question is whether anodizing is an absolutely necessary method of corrosion protection of aluminum parts or whether it can be replaced by another form of coating. Experiments in the study of the influence of different anticorrosive coatings on strength and corrosion resistance of joints were conducted on welded, riveted and glue-welded standard samples (with application of glues VK 1 and FL 4S) made from Duralumin D16T (1.5 + 1.5 mm).

Blanks for riveted joints were subjected to sulfuric acid anodizing with filling in bichromate. Anodized rivets of alloy V65 with a diameter of 4 mm with a flush head were used. Riveting was produced with the help of a riveting pneumatic hammer.

Inasmuch as anodizing of welded joints is impossible chemical oxidizing was tested. Blanks of samples before welding were subjected to etching. After welding the samples were degreased by organic solvent and then covered in the bath of the chemical oxidant. Full covering of the internal cavity by oxide film was ensured.

Glue-welded samples were prepared by the method without glue with its subsequent introduction in the clearance. After polymerization of the glue, part of the samples were subjected to sulfuric acid anodizing with filling in bichromate. Another part of the samples was covered by a system of varnish and paint coatings, including etched and degreased surface of parkerizing ground VL02 cold and hot dryings, ground ALG 14 cold and hot drying (three layer), ground AG3AS and enamels PKhV512 (two layer) and KhSA (two layer) cold drying. Control lots of glue-welded samples were tested without anticorrosive coatings.

All shown lots of samples were subjected to three-month corrosion tests in a ⌊er with periodic spraying of a 3% solution of NaCl with addition of 0.1% H_2O_2 at relative humidity 60-80%. After tests in the chamber the samples were additionally immersed in a 3% solution NaCl with 0.1% H_2O_2, where they were held 30 days.

After the influence of the corrosion medium the samples were tested for static shear (Table 83). They were mainly destroyed by shear in the section of the nucleus of the weld point. Investigation of the surface of the cut of the point nucleus and its macrostructure showed full absence in all cases of traces of corrosion in the metal of the weld nucleus and a plastically deformed belt around the nucleus. Therefore static shear strength of samples before and after corrosion tests turned out to be practically identical (Table 83).

Table 83. Breaking load $P_{раз}$ during static shear of joints depending on the form of protective coatings (D16T; 1.5 + 1.5 mm; diameter of nucleus 6-6.5 mm, rivet 4 mm).

Joint	Protective coating	Average breaking load in kg	
		Before corrosion tests	After corrosion tests
Welded double dot	Without coating	1050	1070
	Chemical oxidizing	1100	1080
Glue-welded double dot (glue GK 1).	Without coating	1680	1510
	Anodizing	1650	1560
	Varnish and paint coating	1670	1650
Glue-welded double dot (glue FL 4S)	Without coating	1320	1280
	Anodizing	1300	1280
	Varnish and paint coating	1310	1300
Riveted two-row	Anodizing	850	840

*Overlap 30 x 35 mm.

The state of the external surface and internal cavity of the overlap after corrosion tests was different. Thus, the surface of a welded joint tested without protective coatings had in many places foci of corrosion (general and pitting corrosion). In the microstructure of a section of this joint there were also observed corrosion defeats; in a number of places there was complete failure of the plating layer. Especially dangerous is the corrosion destruction of plating in the zone adjacent to the plastic belt. The surface of chemically oxidized welded test pieces did not have traces of corrosion.

The surface of anodized and painted glue-welded test pieces did not have corrosion defeats. However on external surface of glue-welded test pieces without protective coatings a general corrosion is noted which also did not influence the static strength of the joints (Table 83). On the internal cavity of the overlap, covered by glue there were absolutely no traces of corrosion, which testified to the high protective properties of glues VK 1 and FL 4S from the influence of the corrosionally-active medium. A certain lowering of strength of glue-welded test pieces with glue FL 4S can be explained, apparently, by insufficient water resistance of this glue, not a corrosion defeat of the metal.

For checking this assumption conducted additional experiments in determination of water-resistance of glues FL 4S and VK 1 under conditions of glue-welded joints. Standard glue-welded point samples made from D16T (1.2 + 1.2 mm) with overlap 25 + 25 mm and glue introduced after welding were put directly in water, then after a corresponding holding removed from it and immediately tested for shear at different temperatures.

As can be seen from Table 84, after the direct prolonged influence of water on the layer of glue VK 1 static strength of glue-welded joints is not changed. Analogous is the behavior of a glue-welded joint with glue FL 4S protected by a system of varnish and paint coatings. However, direct action of water on an unprotected layer of

Table 84. Breaking shear load in kg of glue-welded joints D16T (1.2 + 1.2 mm) with protective coatings and without them after the action of water.

Protective coating	Temperature of tests in °C	Joint with glue VK 1				
		Action of water in days				
		0	5	10	20	30
Without coating	20	$\frac{745}{649-863}$	$\frac{745}{640-824}$	$\frac{731}{698-857}$	$\frac{701}{602-813}$	$\frac{743}{625-847}$
	80	$\frac{1030}{773-1175}$	$\frac{896}{723-1095}$	$\frac{935}{890-965}$	$\frac{841}{737-967}$	$\frac{965}{829-1060}$
VL02, ALG 14, AG3AS, PKhV 512, KhSL	20	$\frac{907}{848-1043}$	$\frac{949}{808-1102}$	$\frac{861}{782-937}$	$\frac{893}{800-1080}$	$\frac{859}{737-1083}$
	80	$\frac{832}{747-916}$	$\frac{959}{810-1115}$	$\frac{852}{848-1100}$	$\frac{977}{852-1080}$	$\frac{986}{955-1048}$

Note: Overlap 25 x 25 mm; diameter of nucleus of point 5.5 mm.

Table 84. (Cont'd).

Protective coating	Temperature of tests in °C	Joint with glue FL 4S				
		Action of water in days				
		0	5	10	20	30
Without coating	20	$\frac{710}{681-745}$	$\frac{571}{415-645}$	$\frac{548}{448-720}$	$\frac{465}{395-600}$	$\frac{514}{423-643}$
	80	$\frac{438}{253-548}$	$\frac{375}{334-419}$	$\frac{443}{337-545}$	$\frac{454}{371-573}$	$\frac{417}{370-459}$
VL02, ALG 14, AG3AS, PKhV 512, KhSL	20	$\frac{726}{689-819}$	$\frac{666}{644-703}$	$\frac{670}{590-720}$	$\frac{638}{590-700}$	$\frac{688}{320-725}$
	80	$\frac{512}{346-626}$	$\frac{476}{410-568}$	$\frac{509}{433-584}$	$\frac{446}{414-498}$	$\frac{494}{455-555}$

glue FL 4S causes considerable weakening of the glue-welded joint, especially in the case of raised temperatures. It follows from this that the water-resistance of glue FL 4S indeed turned out to be lower. To ensure sufficiently reliable protection of a layer of this glue in glue-welded joints from water it is necessary to use a system of multilayer varnish and paint coatings.

The surface of anodized sheets of riveted coatings had no corrosion defeats. However the zone of metal directly adjacent to the hole had considerable corrosion on the mating surface of the sheets as well as near the head of the rivet. This confirms the assumption that with hammer (shock) riveting the anode film cracks near the hole, which promotes the development of pitting.

To ensure full coincidence of the angle of conicity of the head of the rivet and the reamed part of the hole is very difficult in production. Investigations of the microstructure of riveted joints showed that in this case there frequently are formed wedge-shaped clearances which holds moisture or another active medium causing corrosion destruction of the surface of the seat under the rivet.

Considering the above-described character of corrosion defeats of elements of welded, glue-welded and riveted joints, it was possible to expect that they are able to essentially lower fatigue strength of joints, since pitting of the metal leads to an increase in the concentration of stress at the surface of the sheet. In connection with this all the above-described samples were tested also for fatigue before and after corrosion tests. Comparative tests were conducted for axial extension in a asymmetric cycle of loading with cycle factor 0.1 on the basis of 10^7 cycles (Fig. 52-54).

Welded joints without anticorrosive treatment before corrosion tests had a fatigue strength of 2 kg/mm^2. On account of corrosion defeats of the surface of sheets the fatigue strength of these joints dropped to 1.4 kg/mm^2. Chemically oxidized welded samples before and after corrosion tests have identical fatigue strength, equal to 2.3 kg/mm^2 (Fig. 52).

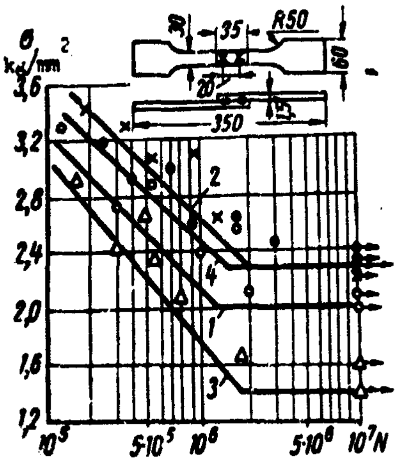


Fig. 52.

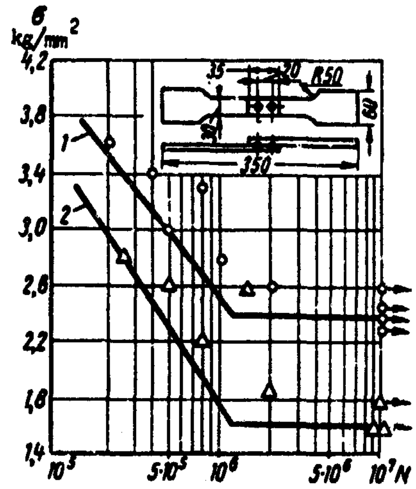
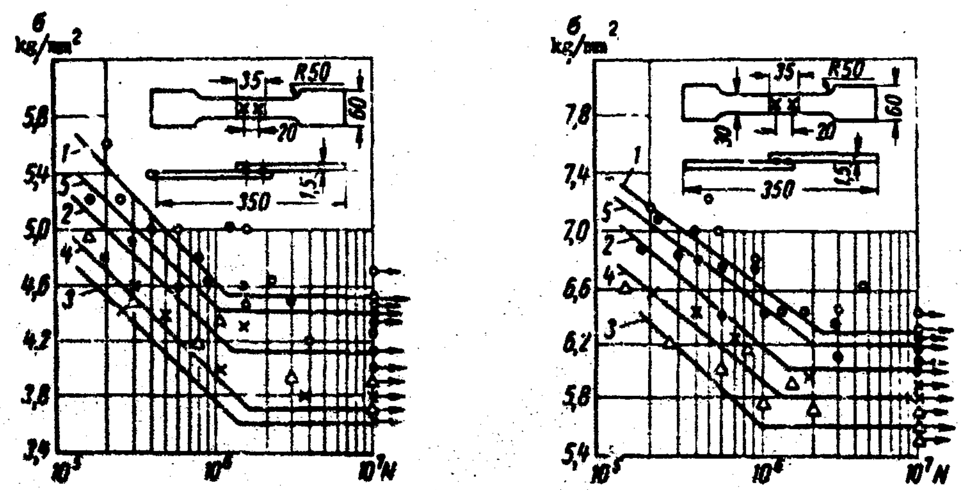


Fig. 53.

Fig. 52. Fatigue strength of welded joints made from alloy D16T (1.5 + 1.5 mm) before and after corrosion tests: 1 and 3 – without protective coatings before (1) and after (3) corrosion tests; 2 and 4 – chemically oxidized before (2) and after (4) corrosion tests.

Fig. 53. Fatigue strength of riveted joints before (1) and after (2) corrosion tests.



a) b)

Fig. 54. Fatigue strength of glue-welded joints of alloy D16T (1.5 + 1.5 mm); a) glue FL 4S; b) glue VK 1; 1 and 3 – without protective coatings before (1) and after (3) corrosion tests; 2 and 4 – anodized before (2) and after (4) corrosion tests; 5 – varnish and paint coating deposited without anodizing after corrosion tests.

Fatigue strength for glue-welded joints with application of glue VK 1 without anticorrosive coverings before corrosion tests and for joints painted after the influence of the corrosion medium is practically the same and is accordingly 6.3 and 6.2 kg/mm^2. Anodizing these connections led to a lowering of fatigue strength to 6 kg/mm^2 without the influence of a corrosion medium and to 5.8 kg/mm^2 after corrosion tests. The least limit (5.6 kg/mm^2) turned out to be for glue-welded unprotected samples after corrosion tests (Fig. 54b).

Qualitatively the behavior of glue-welded joints with glue FL 4S during vibration loads is analogous to the behavior of joints with glue VK 1. Thus, fatigue strength for joints without coatings before corrosion tests for connections colored after the influence of the corrosive medium is practically identical and is accordingly 4.5 and 4.4 kg/mm^2. Anodized glue-welded joints without the influence of the medium have a fatigue strength near 4.15 kg/mm^2 and after corrosion tests 3.7 kg/mm^2. The least fatigue strength (3.6 kg/mm^2) turned out to be for glue-welded unprotected samples subjected to a corrosion effect (Fig. 54a).

As was also assumed, pitting of the metal near holes under the rivet caused an essential lowering of fatigue strength (from 2.4 to 1.6 kg/mm^2) of riveted samples subjected to corrosion (Fig. 53). This indicates that reevaluation of the protective properties of anodization without application of additional paint should be avoided.

Welded joints chemically oxidized and without protective coatings were destroyed, as usually, at the border of the weld nucleus point. For glue-welded joints in all cases destruction in the sheet was usually at the edge of the overlap, i.e., in the zone remote from the nucleus of the weld point.

Thus, the complex of conducted investigations permits making a conclusion concerning that the least degree of change of strength characteristics of welded joints comes from chemical oxidizing, and for glue-welded joints, varnish and paint coating. Anode oxidizing

in sulfuric acid lowers by 10-15% the fatigue strength of glue-welded joints and does not ensure the guaranteed protection of most corrosionally susceptible places in riveted joints. Practically, application of chemical oxidizing is limited strength of the obtained oxide film. Therefore the most promising method of anticorrosive protection of glue-welded joints is considered to be varnish and paint coating without preliminary anodizing. Realization of these recommendations in practice will allow considerable simplification of the technology of manufacture of glue-welded constructions and expansion of the area of their application.

CHAPTER V

MANUFACTURE OF GLUED-RIVETED JOINTS FROM ALUMINUM ALLOYS

Riveted Joints

Riveting until recently was one of the most widely spread methods of producing permanent joints. As it is known, the process of riveting involves upsetting the protruding part of the body of the rivet and formation of a snap head of the required shape and dimension from it. Technology of connection of parts by rivets consists of the following basic operations: drilling or punching a hole under the rivet; countersinking or stamping seats under the set head of the rivet during flush riveting; inserting the rivet into the hole; tension of riveted parts (sheets) and formation of snap head, i.e., strictly riveting; quality control of the joint.

For connecting parts made from aluminum alloys we use cold riveting, during which the rivets are not heated. This provides the best filling of the hole by the rivet body, mechanical properties of the materials are not lowered and production of the riveting operations themselves is considerably facilitated. Work of the riveted joint with respect to the character of transmission of load is equated to the work of pure bolts.

Steel parts and other structural elements are connected together basically by means of hot riveting, during which the rivets heated to a temperature of 1000-1100°C. With the formation of snap heads in the

process of work of the riveting bracket the body of the rivet still soft from heating, being compressed from the blows, pushes apart the edges of the rivet holes and fills them tightly. However, often because of insufficiently effective upsetting the rivet during cooling is reduced in diameter, which leads to the formation of positive allowance between the cooling rivet and the hole of the part. Therefore, in riveted joints, made by hot riveting, forces on the first stage of work of the rivet are transmitted with the help of friction. The set rivet during cooling transmits heat to the surrounding metal and heats it to considerable temperatures. Slow cooling of the bulged riveted metal leads to sharp elastic deformation and the formation of cracks.

Hot riveting is considerably more complex than cold. It requires strictly regulated and uniform heating of the steel body of rivets in special hearths or furnaces, much attention during removal of the hot rivets from the hearth (furnace) by tongs and their driving in by a sledge hammer (hammer) into the hole of parts in connection with increase of the diameter of rivet from heating, etc. Along with this, hot riveting has certain advantages. During cooling the rivet is shortened in the joint and energetically presses the sheets of the riveted stack. From intensive pressing and heating by the rivet the sheets at the place of contact pass the stage of flow and start to work plastically, which causes shift of the sheets and formation of large friction forces. This promotes monolithic work of the riveted joint in the construction. However, with widely spaced arrangement of rivets the considerable compression of sheets causes the formation of waviness of metal between rivets, into which in the process of utilization of the article there can get moisture, corrosion-active gases and can promote corrosion destruction of metal in the cavity of the overlap.

For cold riveting we use rivets made from plastic aluminum alloys (Tables 85 and 86) with protruding and countersunk set heads. They are normalized and have a definite code, indicating the shape of set head, brand of material, diameter and length of body. Rivets are made from wire by heading on special automatic heading machines.

After heading and removal of burrs the rivets are heat treated, and then covered with anitcorrosive protective films (rivets from light alloys are anodized, and from steels – galvanized and passivated).

Table 85. Mechanical properties of rivet wire (hardened and aged) from aluminum alloys.

Material	Temperature of test in °C						
	20			100	150	175	200
	τ_{cp} in kg/mm kg/mm^2	$\sigma_в$ in %	$\sigma_в$ in kg/mm^2	τ_{cp} in kg/mm^2			
D18	21	25	31	18	17	—	14
V65	27	25	42	25	22	20	19
D16P	31	22	49	29	27	26	—
V94	32	14	52	30	27	—	—
D19P	29	23	47	28	27	26	20
M40	29	18	43	50	—	32	28
VAD23	30	5	56	50	47	—	39
AMTs*	10	22	13	—	—	—	—
AMg2*	12	25	6	—	—	—	—
SAP1**	15	4	29	—	—	—	—

*Without heat treatment.
**Annealed.

Table 86. Properties of materials [16].

Material	Standard value of tensile strength $\sigma_в$ in kg/mm^2	Experimental value $\kappa_{cp} = \frac{\tau_{cp}}{\sigma_в}$
D18T	30	19–21
V65	40	22.5–24
V95T	50	25

Rivets made from alloys D18, V65, V94 are heat treated once and are placed in construction after completion of the process of natural aging. For example, rivets from alloy D18 are placed in construction not earlier than 4 days from the moment of their heat treatment. Rivets from Duralumin D16P and D19P are placed in construction in freshly hardened state, while rivets 3-5 mm in diameter should be riveted no later than 6 h after quenching. Rivets subject to repeated

heat treatment are not used during this time. Rivets made from alloy M40 are placed in construction in hardened state. These rivets, in contrast to other durable aluminum rivets, after quenching are suitable for use a long time (under the condition of their storage at room temperature). The heat resistance of rivets from alloys M40 and VAD23 exceeds that of rivets made from other aluminum alloys (Table 85).

For hot riveting we use steel rivets. Most often we use steels 20GA, 15A, 30KhGSA and others. Rivets made of steel 15A are placed in construction in tempered state, and from steel 30KhGSA (highly durable) – in hardened state.

Force necessary for the formation of a snap head in the process of riveting (Table 87) is calculated by the following formulas:

for flat head

$$P = 2{,}5\sigma_{в} d_{з}^{2},$$

for round head

$$P = 5{,}3\sigma_{в} d_{з}^{2},$$

where P – compressing force in kg;

σ_B – tensile strength of material of rivet in kg/mm^2;

d_3 – diameter of rivet in mm.

Table 87. Force P in kg, necessary for the formation of snap head of rivet from alloy V65P.*

Shape of snap head	Diameter of rivet in mm	
	3	4
Flat	790	1400
Spherical	—	2960

*Compressive strength of alloy 35 kg/mm^2.

Glued-Riveted Joints

To ensure the required strength of metal riveted constructions it is necessary to set rivets with small spacing, and also to apply of multiple seams. This causes a large enpenditure of rivets, lowers productivity of the process, makes the construction heavier and weakens the section of riveted elements by a large number of holes.

It is very complicated to rivet a stack consisting of long structural elements. When setting rivets in holes in long elements, made preliminarily in a large quantity, there often occurs misalignment of holes due to mutual displacement of parts in the stack, formation of waviness (flakes), bulging forces, appearing during the formation of snap heads of rivets, etc. For elimination of this phenomenon in many cases it is necessary to drill holes through jigs with thorough fixation of the position of thin-sheet facings with respect to the frame with help of complex clamping attachments. However, even here there is possible the appearance of "flakes" during loss of stability of facing due to bulging out of the walls of the hole during the formation of snap heads and deformation of the body of rivets.

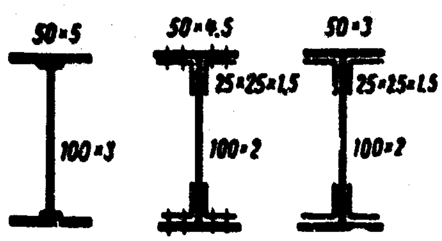
Riveted joints are very complicated to hermetically seal. Even through thoroughly sealed riveted joints there often occurs leakage of air and liquid. Danger of disturbance of airtightness of the riveted seam is increased by the tendency of riveted sheets to buckle under load, inherent to riveted joints. Leakage of air or liquid through the riveted seam can occur through gaps between the joinable parts, gaps between walls of the hole and body of the rivet, gaps between the surface of the part and set head of the rivet. Riveted constructions (Fig. 55) with respect to efficiency during static and cyclic loads, and also with respect to economy are inferior to welded and glued (Table 88) [40].

In the cavity of the riveted joint of parts from aluminum and magnesium alloys, not having protective coatings, there is possible the formation of electrochemical corrosion from capillary moisture, penetrating the overlap.

Table 88. Efficiency of constructively uniform steel I-beams (Fig. 55) during static and cyclic loads.

Elements of beams	Riveted	Welded	Glued
Dimensions in mm: wall.. horizontal sheets (webs).................... corners.....................................	 2×100 4.5×50 25×25×1.5	 3×100 5×50 —	 2×100 3×50 25×25×1.5
Moment of resistance in cm^3....................	30	30	30
Section in cm^2................................	9.5	8	8
Sag in mm (during static load 1500 kg; length of span of beam 800 mm)......................	2.24	1.85	1.98
Endurance bending strength in kg/mm^2 (on the basis of 10^6 cycles)........................	4.5	3.5	10

At the contemporary level of development of riveting technology in connection with the deficiencies inherent to it the operational and technical requirements cannot be completely satisfied. In recent years in domestic and foreign technology a new improved type of permanent connection of parts from aluminum alloys and steels has started to find increasingly wider application – glued-riveted joints, produced as a result of combination of the technological processes of cold riveting and gluing of metals. In this case the advantages of riveting and gluing are used to the maximum and many important deficiencies, inherent to each of these processes separately, are excluded.



a) b) c)

Fig. 55. Construction of I-beam: a) welded; b) riveted; c) glued.

Combined – glued-riveted joints with respect to their physical and mechanical and technological properties will be compared favorably

with standard riveted and glued joints. Thus, they possess higher strength both during static loads (Tables 89 and 90) and during vibration loads (Fig. 56), and are also airtight, lighter (as compared to **riveted**) and fire-proof (as compared to glued). During loading of a glued-riveted joint the glue layer, monolithically fastening the mating parts over the entire area of overlap, absorbs a considerable part of the stresses unloading the rivet and promoting increase of their efficiency, and also lowers deformation of sheets (especially of smaller thickness) in the stack.

Table 89. Shear breaking load in kg of lap joints of alloy AMg6.*

Combination of thickness in mm	Joint				
	riveted	screw	glued-riveted	glued-screw	glued-welded
Glue EPTs					
1+1	255	335	475	560	530
1.5+1.5	390	500	650	725	850
2+2	510	675	700	875	1040
1+2	260	335	480	560	560
Rubber glue					
1+1	255	335	490	570	—
1.5+1.5	380	500	660	740	—
2+2	510	675	765	880	—
1+2	260	335	500	565	—

*Amount of overlap 25 × 25 mm. Diameter of rivets from alloy D18T and steel screws 25-4 mm.

Table 90. Shear breaking load P of samples from glass-base textolite (1.5 + 1.5 mm), made into lap joint on glue L4 (according to F. A. Smirnova and I. Z. Chernin).*

Joint	Condition of gluing	P in kg
Glued-riveted	Holding of joint before riveting 2 h without pressure	1164±80
	Holding of joint before riveting 24 h at contact pressure	1083±115
Glued	Holding of joint at contact pressure for 24 h	1084±112

* Amount of overlap 40 mm; width of sample 45 mm; diameter of flush rivets from alloy AMTs 4 mm.

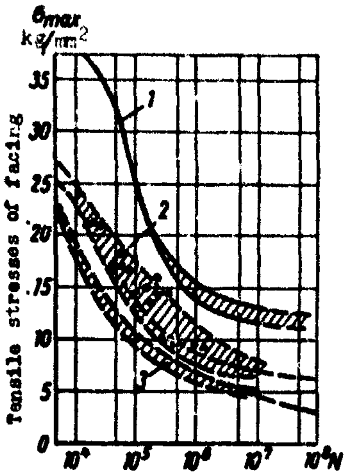


Fig. 56. Strength of glued-riveted joints during vibration loads: 1 - facing from aluminum alloy 24 S-T; 2 - glued-riveted joints on film of ridaks; 3 - riveted joints with three or more rows of rivets.

Redistribution of stresses considerably decreases their concentration at borders of the rivet, increases the strength of connection, especially during cyclic loads (Fig. 56). Thanks to increase of efficiency of rivets their quantity can be noticeably decreased in the glued-riveted seam, which accordingly leads to lowering of the weight of construction and to decrease of the labor-input of manufacture of the article.

The chemically stable glue layer, filling the clearance of the glued-riveted joint, reliably protects the internal surface of the mating parts from corrosion and makes it airtight. To ensure especially reliable airtightness of the glued-riveted joint we recommend [14] in a number of cases to additionally place under the rivet heads washers punched from thin glue films (0.05-0.1 mm), or to cover the support part of the head with liquid glue, which not allowing the glue to get on the surface of the head. Good results are given by application of thin bands of glue or sealer on edges and butts of the glued-riveted joint with the help of a gun or brush immediately after making the joint (before hardening of the glue layer).

In contrast to glued, the glued-riveted joints ensure prolonged reliable efficiency of constructions (lowering of the strength of glued joints with passage of time is known). The presence of rivets in the combined joint also improves work of the glued seam under conditions of nonuniform breaking.

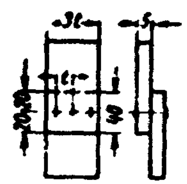
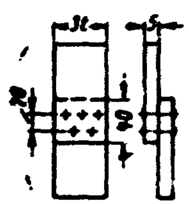
It is very difficult to rivet long structural elements especially if they consist of thin-sheet facing and a rigid frame. Combination of riveting with gluing permits considerably simplifying the process of manufacture of similar construction. Thus, preliminary gluing (before riveting) of thin facing to elements of the frame permits drilling holes under rivets in a monolithic (i.e., glued) stack of parts without the application of clamps and other complex fixing attachments. In this case misalignment of holes during setting of rivets is almost completely excluded.

Rivets in glued-riveted joints, being the basic supporting elements can simultaneously carry out (when necessary) pressing of the glue layer in it, hardening process. Glued-riveted joints are very effective when joining not only metallic, but also nonmetallic structural elements, and also when combining metals with different structural nonmetallic materials.

As experiments showed, it is very complicated to ensure sufficiently durable connection of parts from nonmetallic materials with riveting alone because of the considerable difference of elastic moduli of the material of rivets and the material to be joined. The latter is mashed inside the holes and under the rivet heads, causing its misalignment, and in many cases bending of the body of the rivet. A sufficiently effective method of connection of parts from nonmetallic materials is gluing. However, glued joints, possessing high strength when working on pure shear and breakaway, poorly resist nonuniform breaking loads. Therefore, it is necessary to set rivets in outer zones of overlap of glued joints.

In contrast to purely glued and riveted joints, glued-riveted joints of parts from nonmetallic materials possess higher strength when working both on shear (Tables 90 and 91), and on uniform and nonuniform breaking, while strength indices of the joints essentially depend on the gluing conditions (Table 90) and spacing of rivets (Table 91). With respect to strength the glued-riveted joints with single and double rivet weld at identical amount of overlap differ

Table 91. Shear breaking load P of glas-base textolite joints with single and double seam.*

Construction of joint	Combination of thickness in mm	Spacing of rivets in mm	P in kg: riveted joints	P in kg: glued-riveted joints	Character of failure of joints: riveted	Character of failure of joints: glued-riveted
	1+1	10 15	290±5 297±20	501±30 815±30	Crumpling of glass-base textolite along tie pieces	Crumpling of glass-base textolite along tie pieces
	1.5+1.5	10 15	193±7 225±10	865±40 1060±50	The same and shear of rivets	The same
	2.5+2.5	10 15	290±5 310±10	895±33 1157±50	Shear of rivets	Shear of rivets
	1+1	10 15	488±20 480±5	525±10 665±30	Crumpling of glass-base textolite along the pieces and shear of rivets	Failure of glass-base textolite along tie pieces
	1.5+1.5	10 15	495±5 446±10	770±30 1200±50	Shear of rivets	The same
	2.5+2.5	10 15	485±5 475±10	600±20 1350±50	The same	Shear of rivets

*Distance between rows of rivets 20 min

insignificantly. This is caused by small spacing between rivets (10 and 15 mm), with which there is ensured sufficient pressing of the glue layer, but the section of the joined stack of sheets is weakened by holes under rivets and the working area of the glued seam is decreased. Higher efficiency of glued-riveted joints in constructions from nonmetallic materials is provided in the case of setting rivets with considerably large spacing, which is shown in Table 91. Thus, for example, during manufacture of glued-riveted joints from glass-base textolite, fiberglass and other similar materials 1-2.5 mm thick it is rational to place the rivets with spacing 40-60 mm.

Technology of Manufacture of Equipment

Glued-riveted joints in constructions can be made basically by two methods: 1) setting of rivets on an earlier made glued joint with completely hardened glued seam; 2) setting of rivets on nonhardened liquid glue or glue film applied earlier on mating surfaces with their subsequent hardening already in the combined joint.

The first method ensures more uniform forming of the glue layer in the joint and excludes the possibility of formation of unglued areas, which contributes to obtaining combined joints with higher and more stable strength. In this case the glued-riveted joints are made in the following way. Structural elements are assembled in a building slip (or without it), fixed and then preliminary holes are drilled in them under rivets of several smaller dimensions than on the drawing. After this the elements are removed from the building slip, degreased, chemically or mechanically treated prior to gluing and liquid or paste-like glue is applied on the mating surfaces. Then the elements are again assembled, fixed and glued by the usual method under conditions corresponding to the given glue. After this the holes are drilled finally and riveting is produced. It is more rational to use press riveting.

A deficiency of this method is the fact that there is possible damage of the glue layer during the formation of holes, setting of

rivets and their unriveting, especially by pneumatic hammers, which lowers the strength of joints and disturbs their airtightness. Furthermore, very strict observance of gluing conditions is required. The strength of glued-riveted joints is negatively affected by insufficiently uniform compression of the glued stack of sheets.

Uniformity of compression of glued sheets depends on the quality of trimming of the surface of parts, conditions and methods of transmission of the pressures of press fitting, and also the shape and overall dimensions of structural elements. The last circumstance frequently excludes the possibility of application of simple standard equipment for this purpose. It becomes necessary to develop and to manufacture special attachments, corresponding to the shape and overall dimensions of the given article, which increases labor-input and the production cost of articles.

The second method of manufacture of glued-riveted joints is simpler and is technologic, since it does not require special attachments and bulky equipment for pressing of glue. Pressure on the glue layer in its hardening process is created by the rivets themselves, set on liquid glue or unhardened glue film. However, in this case there will be formed a glue layer of nonuniform thickness, and at separate places there appear nonglued, areas especially when riveting parts less than 2.0-1.5 mm thick, and also thin-sheet facings with elements of a rigid frame. In connection with this, the combined joints, made by the second method, in a number of cases possess somewhat lowered and insufficiently stable strength.

The manufacture of glued-riveted joints in constructions from aluminum alloys by the second method is recommended to carry out according to the following flow diagram: 1) marking of parts of node; 2) drilling of holes under rivets (when necessary also countersink); 3) chemical treatment or machining of mating surfaces prior to gluing (electrochemical oxidizing or anodizing, stripping with emery paper or mechanical wire brush) depending upon the glue used and area of surface to be glued; 4) check (preliminary) assembly and fixation of

the structural element, then its disassembly; 5) application of liquid glue on the mating surfaces; 6) final assembly of the node and riveting.

As experiments showed, to avoid the formation of cracks in the hardening glue layer, and also for reducing the danger of appearance of nonglued areas, it is necessary to produce riveting on a layer of liquid, paste-like or film glue strictly within limits of adhesive working life (i.e., before the beginning of the process of polymerization).

With the second method the glued-riveted joints in separate cases can also be made by such a flow diagram: 1) degreasing; 2) drilling of holes only for fixation of parts; 3) chemical treatment or machining; 4) application of glue or packing of glue film; 5) assembly of node, fixation of its elements and marking; 6) drilling of holes under rivets and riveting.

Along with the above-described methods in a number of cases it is possible to manufacture glued-riveted joints similar to glued-welded, by method of capillary introduction of glue into the cavity of overlap after setting of rivets. Essence of this method and it technology are described in Chapter III. The given method is especially suitable to use during repair works in structural elements and nodes, ensuring two-sided approach to edges of the riveted joints.

It is established experimentally that the quality of glued-riveted joints, made both by the first and second method, highly depends on correct selection of the length of rivet, method of upsetting the protruding part of its body and the formation of a snap head.

Incorrect selection of the rivet length lowers the strength and disturbs the airtightness of joints. Increase of rivet length over optimum causes deformation (bending) of its body with the formation of a snap head, which excludes close fitting of mating parts because of weak compression and, consequently, does not provide sufficient press

fitting pressure on the glue layer (particularly when riveting on a layer of liquid or paste-like glue). With a shortened rivet there can either be formed inferior snap heads or extremely close fitting mating parts because of strong compression.

Excessively high specific pressure on the hardened (with the first method) or damp glue layer (with the second method) is also impermissible. The hardened layer will be destroyed during this in the zone directly adjoining the rivet, and damp – will be forced from the indicated zone to a considerable distance (depending upon the thickness of joined sheets) in the peripheral sections, forming nonglued areas. Furthermore, because of raised specific pressure there appear considerable internal stresses in the riveted elements, which create breaking forces and force the glue layer to work under conditions of nonuniform breaking. As a result the glued seam becomes short-lived.

Length of rivet L is selected according to the following relationship:

$$L = 1{,}3S + d_з,$$

where S – total thickness of the riveted stack of parts in mm;
d_3 – diameter of rivet in mm.

During cold riveting, for example, of thin-sheet facings with rigid frame elements because of deformation of the extended body of rivets there appear considerable bulging forces, leading to local loss of stability (buckling) of facing and, consequently, to nonglued area between the rivets; this bulging out is the most noticeable for a snap head and less – for set head. From this it follows that when designing an article it is necessary to place the snap head on the side of the sheet with greater thickness. Appearance of bulging out, causing local nonglued area of facing with elements of frame, also depends very much on the method of riveting used and the quality of carrying it out.

Direct and reverse methods of percussion riveting are known and are comparatively widely used in practice. Reverse method of riveting, allowing for application of blows by a pneumatic hammer on the side of the set head, is unaccpetable for production of glued-riveted joints, especially by the first method (riveting on hardened glue layer). This is caused by the unfavorable effect of blows of the hammer on the glue layer in connection with transmission of them through setting directly to the riveted sheets (on the side of the facing). Insignificant slant or misalignment of setting causes deformation of thin-sheet facing, due to which the brittle hardened glue layer is damaged. This appears especially strongly during hand riveting, the quality of which highly depends on personel data of the worker-riveter (qualification, fatigue, etc.).

With increase of the weight of bucker the quality of riveting is considerably increased and the danger of damage of the glue layer is reduced. However, the worker-riveter is rapidly fatigued during this, the quality of riveting is lowered in connection with this and the danger of damage of the glue layer is increased because of possible misalignments of the riveting tool. Weight of the bucker is noticeably increased with increase of the diameter of rivet. Thus, in case of the direct method of percussion riveting with diameter of aluminum rivet 2.6 mm the weight of the bucker is 5 kg, at 3.0 mm 6 kg, at 4.0 mm 8 kg and at 6.0 mm 12 kg; in case of the reverse method at 2.6 mm 1.3 kg; at 3.0 mm 1.5 kg, at 4.0 mm 2 kg, at 6.0 mm 3 kg.

In the process of reverse percussion riveting on a layer of liquid glue (second method) the dents forming from setting cause local nonglued areas and concentration of stresses in the combined joint.

Use of direct percussion riveting for the manufacture of glued-riveted joints by the first method is also inexpedient in connection with possible damages of the hardened glue layer. However, the application of direct riveting on a layer of liquid or paste-like glue (type VK 9 with 10-15 parts by weight of filler) within limits

of its adhesive working life with enclosed holdings is fully permissible.

Percussion riverting has essential deficiencies (causes mass occupational illnesses of workers-riveters - deafness, vibration sickness, etc.). Therefore, in recent years research has been conducted in the creation of improved, progressive percussion riveting equipment, allowing considerable improvement of labor conditions of workers-riverters and increase of productivity of the process. For example, there is developed pneumatic hammer MK-9 with vibration of working elements lowered 2-3 times. This hammer weighing 3.2 kg operates with air pressure in the line 5 at and develops impact force 3 kg-m. At the Gor'kiy automobile plant there is proposed a low-noise riveting tool, for which the exhaust air heads into a muffler. Besides this, domestic industry has developed and mastered versions of riveting hammers with a new improved air-distribution system: KMU 11, KML 22, EKM 4 and others. For convenience of operation there are manufactured riveting hammers, distinguished by small weight and overall dimensions: KMP 11, KMP 21, KM 2, KM 31 and others.

In Table 92 there are listed specifications of certain types of new domestic pneumatic impact hammers, recommended for use in the production of glued-riveted joints. They possess insignificant dimensions and weight and permit riveting on damp glue in a node of practically any complexity with installation of the article and its assembly in a building slip.

Manufacture of glued-riveted joints by the first method (riveting on hardened glue) is the most expedient with the aid of press riveting (if construction of nodes permits). During this riveting the formation of snap head occurs as a result of gradual uniform compression of the rivet body, due to which the possibility of damage of the hardened glue is excluded and, consequently, high-quality combined joints are obtained. Furthermore, there also ensured more denser and uniform filling of holes by the body of rivets and thereby transmission of forces to the glue layer is improved, which contributes to increase of efficiency of the glued-riveted joints.

Table 92. Specifications of pneumatic percussion riveting hammers for unriveting rivets from alloy V65 with diameter up to 5 mm (pressure in line 5 at).

Type of hammer	Weight in kg	Average time of riveting in s	Lenth of hammer with setting in mm	Vibration safety factor	Heat shielding
Thickness of stack 5 mm					
5KM	1.1	1.6	135	0.71	None
1MA	0.95	1.6	135	10--12	Polyethylene and caprone
Thickness of stack 10 mm					
57 KMP5	2.1	1.6	280	56	Chamois
2MA	1.5	1.2	223	13—15	Polyethylene and caprone

Note: Hammers are equipped with vibration damping device, which lowers the recoil of impact to the hand of the worker when riveting.

Formation of snap heads of the riveted seam after bonding of parts eliminates the danger of shift of these parts relative to each other, which can occur during riveting on damp glue.

Manufacture of holes in the glued stack ensures their alignment along the entire length of sheet facings in large-sized panels and eliminates the necessity of application of complex jig and fixing attachments. Uniform pressure, directed along the axis of the rivet body during press riveting, allows any position of the set relative to snap and set heads. In contrast to percussion, press riveting does not create harmful industrial noise, permits forming snap heads on several rivets simultaneously (during multiple riveting), a manual laborer is not required, which sharply increases productivity of the process.

In a number of cases glued-riveted joints can be manufactured by press riveting and by the second method (riveting on damp glue). Press riveting can be carried out on hand presses and on machines. Single riveting is carried out on stationary machines and portable hand lever presses. The expediency of application of hand or stationary

presses depends on the construction of subassemblies of the article, method of manufacture of glued-riveted joints, type of production, etc.

For the manufacture of combined joints in small and large preliminarily glued nodes with small overlap it is recommended to use portable hand pneumatic lever riveting presses of type PRP possessing small overall dimensions, weight (2-3 kg) and is easily moved in the working process.

Specifications of the most widely spread presses are listed in Table 93. During manufacture of glued-riveted joints with application of rivets 3-5 mm in diameter from aluminum alloys D18T, D19 and V65 for formation of snap head there are already required comparatively high forces. Thus, with diameter of rivet 3 mm there is required force 940 kgf, at 3.5 mm 1340 kgf, at 4 mm 1980 kgf, at 5 mm 2980 kgf. With series manufacture by the first or second method of large-sized glued-riveted constructions with various overlap it is recommended to use stationary pneumatic lever presses with single and multiple semiautomatic and automatic riveting, equipped with levelling devices (KP 204, KP 603 and others). For example, on KP 603 press by the first method it is possible to manufacture flat and round glued-riveted elements from aluminum alloys up to 24 m long and up to 3 m wide.

Table 93. Specifications of hand pneumatic lever riveting presses.

Indices	PRP 11	PRP 24	PRP 27
Developed force in kgf	2000	4500	1500
Movements per minute	15—20	15—20	20—25
Geometric dimensions of clamp of press in mm:			
overhang	35	55	35
throat	25	35	25
Diameter of rivet in mm	4	6	3.5
Weight of press in kg	3	6	2.2

Technology of manufacture of glued-riveted constructions by press riveting with the second method (riveting on damp glue) is more complex than with the first. With the second method the panel or node enters riveting in assembled and fixed form with rivets

preliminarily inserted in the holes. To avoid possible outflow of glue from the cavity of joints it is necessary to strictly watch that the panel in the process of riveting in horizontal position or slanted to the horizon (by not more than 15-20°) For this reason the nodes, having considerable curvature, are practically impossible to manufacture by press riveting on stationary presses by the second method.

At present our industry also has available universal automatic riveting machines (for example, SKA1 type), fulfilling an entire complex of operations: drilling and countersinking of holes, automatic adjustment of special mechanisms for formation of the required height of snap head, riveted nodes of articles with different types (with respect to diameter and length) of rivets, etc. Application of these automatic machines is rational and very effective during the manufacture of glued-riveted joints only by the first method (riveting on hardened glue). Riveting on the indicated automatic machines on a layer of liquid or paste-like glue is connected with a whole series of difficulties. Thus, the riveted node is placed, for example, in SKA1 automatic machine vertically, which causes an inevitable outflow of glue (even thickened) from the cavity of the riveted seam and, consequently, lowering of the quality of the connection. The outflowing glue soils the article and elements of the machine, and can also fall into the drill-counterbore heads, cause breakdown, etc. (hardened synthetic glues are very difficult to remove from metallic surfaces).

Rivets for Glued-Riveted Joints

For manufacture of glued-riveted joints we use standard rivets, and also special, subdivided into two basic groups depending upon their purpose: with two-sided and one-sided approach.

Rivets with two-sided approach, so-called rivets with high shear strength, are used in power joints, absorbing large shearing force, and also instead of standard (rod) aluminum rivets of large diameter. In such joints the application of standard (rod) steel rivets is technologically irrational, since it is necessary to heat them before

setting in a hole. This leads to carbonization or burning out of the glue layer around the rivet.

Use of standard aluminum rivets of large diameter highly weakens the section of the riveted stack of parts with holes. Furthermore, in this case considerable forces are required for the formation of snap head, which often causes damage of the glue layer (when riveting on hardened glue), and also excludes the possibility of riveting with the use of comparatively simple portable equipment and causes the necessity of application of powerful bulky equipment. When unriveting rivets of large diameter there are also sharply increased bulging forces from flattening of the rivet body, transmitted to walls of the hole, which causes increase of stresses in the glue layer and its cracking.

Rivet with high shear strength consists [5] of steel heat-treated body 1 and ring 2 from aluminum alloy D18 (Fig. 57). Body of the rivet on one end has a flat or countersunk set head; on the other end it is equipped with special neck, ensuring reliable attachment of snap head on the rivet body, formed as a result of upsetting the aluminum ring.

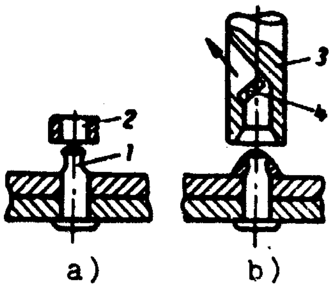


Fig. 57. Diagram of the riveting process using rivets with high shear strength: 1 – body of rivet; 2 – ring from aluminum alloy; 3 – set; 4 – removal of (excess) material of ring.

The process of riveting with this type of rivets is carried out on usual riveting equipment. Besides there is used a special set, equipped with a hole for exit of excessive material of the ring after its upsetting on the rivet body (Fig. 57b). Before setting in a hole the rivets are dipped in glue for sealing the combined joint and preventing electrochemical corrosion between the steel rod and aluminum snap head of the rivet.

Glued-riveted joints with the application of special rivets with two-sided approach can be made by the first or second method described above.

Rivets with one-sided approach (hollow) are used during the manufacture and especially during repair of constructions where two-sided approach is excluded (tubular nodes, different containers, wing-tips, etc.). Hollow rivets are especially widely used as auxiliary.

There are known several different types of rivets, utilized for blind riveting. However, as analysis of source material and conducted experiments shows, for production of glued-riveted joints only certain types of these rivets, ensuring sufficiently high tightening forces, are suitable.

The most promising for production of glued-riveted joints is the type of rivets shown in Fig. 58a. In the cavity of the hollow body of the rivet before the formation of snap head we introduce a steel or aluminum rod, and then perform blind riveting with the help of hand tongs or a portable hand pneumatic lever press. With this the core, being press fitted with much force into the body of the rivet (Fig. 58a), will form a reliable snap head. In this case there is not required close fitting (trimming) of sheets in the stack. Thanks to considerable tightening forces the parts with a glue layer between them are tightly fitted to each other, creating the required specific pressure on the glue layer. Application of these rivets is possible in a combination with thermosetting and self-setting glues. The shown rivets are widely used, especially in foreign technology, for connection of thin-sheet structural elements from aluminum alloys [22].

It is recommended to make glued-riveted joints with application of the described rivets by the following scheme. Preliminary assembly of the structural elements, fixation, manufacture of holes under rivets in them by a standard tool, disassembly, application of glue on mating surfaces, final assembly, gluing, setting of rivets in holes with core inserted in their cavity and riveting.

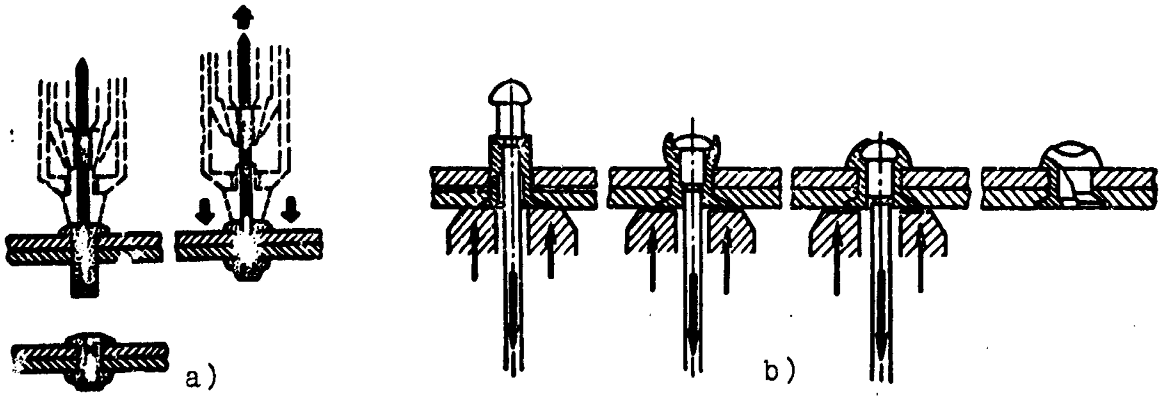


Fig. 58. Proceed of riveting with hollow rivet: a) with core; b) with splitting.

For manufacture of glued-riveted joints in thin-sheet construction it is possible to use so-called rivets with splitting (Fig. 58b) [22]. In the body of such a rivet there is preliminarily made a tapered hole, into which in the process of riveting we drive a metal core with a hammer. On the opposite end of the rivet (internal surface of the construction) there is a slit, promoting its best splitting when driving in the core. Rivets are placed in holes preliminarily made on the parts after application of glue on the mating surfaces.

Along with the described rivets for production of glued-riveted joints considerable interest is also presented by hollow rivets, having smooth internal cavity or equipped with female thread (Fig. 59) [22]. Fastening of joinable parts in a stack occurs due to increase of the section of rivet and bulging of its protruding part. In a threaded rivet when tightening the core screwed into the cavity there will be formed a snap head.

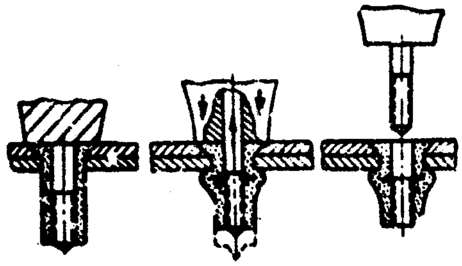


Fig. 59. Process of riveting with hollow rivet, equipped with female thread.

During repair of a number of constructions under field conditions it is recommended to use special rivets with one-sided approach combined with BF2 glue film, reinforced by caprone gauze. This permits increasing the strength and airtightness of a glued-riveted joint 2-3 times as compared to the strength of a glued-riveted joint made with the application of usual liquid glue BF2. The presence of caprone gauze in the glued seam sharply lowers shrinkage stresses and its tendency of crack formation in the process of operation of the article.

For manufacture of glued-riveted joints with application of the described rivets with one-sided approach in foreign technology [22] there are widely used lever hand tongs or pneumatic hand process.

Hand tongs provide qualitative glued-riveted joints with diameter of core up to 4 mm. With the help of such tongs the core is drawn inside the cavity of the rivet, tightens the stack of parts by deformation of wall of rivet and forms a snap head (Fig. 58a); the unnecessary end of the core is bit off and is ejected outside by the tongs. The tongs can be used also for making glued-riveted joints with rivets shown in Fig. 59. In this case there is ensured a durable connection with application of a steel threaded core with 3-5 mm in diameter and from aluminum alloys – up to 6 mm. Especially convenient are lever-hinged tongs, developing the greatest force during riveting and allowing manufature of glued-riveted joints with bigger rivets (with diameter of core up to 4 mm). Hinged arrangement of tongs gives the possibility of changing the length and of riveting under different conditions.

With hand pneumatic presses it is possible to make glued-riveted joints by hollow rivets with core 3-5 mm in diameter. The press provides high productivity (unrivets 25-30 rivets per minute at pressure 6 at), automatically rejecting the bit-off parts of cores. When riveting parts from aluminum-magnesium alloys with hollow rivets it is recommended to select the length of cores in accordance with the following data [22]:

Length of core* in mm	3,5	4,5	5,5	6,5	8	10	12
Total thickness of sheets in mm	0,5–1,5	1,5–2,5	2,5–3,5	3,5–4,5	4,5–6,5	6,5–8	8–10

*Diameter of core 3 mm; diameter of hole 3.1 mm; force of tension 150 kgf.

For manufacture of glued-riveted joints by blind riveting in a number of cases it is suitable to use explosive rivets and, so-called bolt-rivet ("lock-rivets"). When setting explosive rivets the snap head will be formed, as it is known, due to force appearing as a result of explosion of the explosive in the body of the rivet (Fig. 60). Explosion is carried out with the aid of a special electric heater. Glued-riveted joints with the application of explosive rivets are rationally made by the following scheme: preliminary assembly of parts, fixation, drilling of holes 0.3-0.5 mm smaller than diameter of rivet, reaming of holes, disassembly of parts, preparation of mating surfaces prior to gluing, application of glue, final assembly of parts, riveting on liquid glue, setting of glue. Use of explosive energy permits making glued-riveted joints with the application of rivets of large diameter.

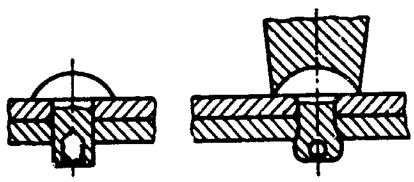


Fig. 60. Diagram of the process of connection of parts with explosive rivets.

Explosive riveting provides the most qualitative glued-riveted joints. Energy of explosion permits deforming the body of the rivet at high speed with formation of snap head, promotes more complete and more uniform filling of holes and thereby ensures raised airtightness and strength of joints. Furthermore, with this riveting there will not be formed dents and damage of the riveted material under snap heads, the appearance of additional internal stresses in the glue layer, unfavorably affecting the quality and strength of the combined joint, is excluded.

Explosive riveting can be used both with single-charge and multiple-charge pneumatic riveting hammers.

One-sided riveting in spite of the expediency of its use during manufacture of a series of complex articles, still find insignificant application in domestic technology, especially in glued-riveted joints. this is caused basically by the high cost of hollow rivets with cores, and also explosive rivets.

Glues for Glued-Riveted Joints

Structure of technology of manufacture of glued-riveted joints and their properties, just as in the case of manufacture of glued-welded joints, in many respects are determined by the physicomechanical and technological properties of the utilized glues.

The conducted experiments, and also analysis of source material show that for manufacture of glued-riveted joints it is rational to use liquid, paste-like and film thermosetting and self-setting glues, possessing a combination of the following basic properties: low viscosity (but not too high fluidity), ability to harden without heating or with minimum hetaing, and also with minimum possible shrinkage to form a dense, nonporous and elastic glue layer in joints not requiring high specific pressures for pressing the glue layer in the joint during its hardening, etc. To these requirements to the greatest degree there correspond glue compositions, composed on the basis of epoxy resins (especically without solvent). Selection of the type of glue is largely determined by the design features of the article.

When making glued-riveted joints by the first method it is possible to use liquid, paste-like and thermosetting film glues: BF2, BF4, MPF 1, VK 5, PU 2, FL 4S, VK 1, VK 1MS, VK 32-200, VK 32-250, VK 3, VK 4, VK 7, VS 10T and VS 350, and also self-setting glues – L 4, KS 609, PU 2, VK 5, KLN 1, EPTs and K 153. Among foreign self-setting glue compositions cyanacrylate glue of brand Eastman 910,

created in recent years, is of considerable interest [45]. The glued seam can set very rapidly is delayed somewhat in the range from 10 s to 24 h (depending upon the character of materials to be glued).

Most of the enumerated domestic thermosetting glues are polymerized at comparatively high temperatures, which must be considered when using them in production of glued-riveted articles. It is the most rational to use self- (warm) setting glues, making it possible to considerably simplify the technology of manufacture of any nodes and articles with glued-riveted joints.

For manufacture of glued-riveted joints by the second method there can be used only those thermosetting or self-setting glues that do not require creation of high specific pressures on the glue layer in the process of polymerization. Thus, for this purpose it is possible to recommend the following domestic thermosetting and self-setting glues: MPF 1, FL 4S, KS 609, PU 2, VK 5, VK 32-EM, L 4, K 153, KLN 1, EPTs, VK 1, VK 1MS, VS 10T, VS 350 and others. With this method it is also the most rational to use self-setting glues.

In foreign technology for manufacture of glued-riveted joints by the second method high heat-resistant two-component phenol-rubber glue Epon 927 recently started to be widely used [41]. It can be used in liquid and film form and is suitable for use 46 days from the moment of preparation. Liquid glue has very high adhesion to aluminum alloys and steels. Glue is able to harden at room temperature in three days and with heating. The glued seam possesses high elasticity (elongation is around 10%) and is able to sustain a temperature of 1040°C up to 10 min.

In case of the manufacture of glued-riveted joints by the method providing for introduction of glue into cavity of overlap after setting of rivets, there can be used only those glues which possess sufficient adhesive working life, low viscosity and good penetrability. As experience has shown, the most suitable for this purpose are glues Fl 4S, VK 1MS, VK 7, VK 1 and partially KLN 1 and KS 609.

During manufacture of glued-riveted joints by blind riveting, and also during their repair it is the most convenient technologically to use self-setting glues (KLN 1, KS 609, EPTs and others), not requiring considerable forces during pressing.

Method of Formation of Holes

The quality of manufacture of glued-riveted joints depends very much on the quality of holes made under rivets. Experiments show that misalignments and deivations of dimensions of holes from specified, and also insufficient cleanness of their walls and edges (the presence of cracks, dents, burrs, chipping of edges, etc.) promotes the appearance of additional internal stresses and miscroscopic cracks in the glue layer during formation of snap heads, which lowers the efficiency of connection.

Holes under rivets in metallic constructions can be drilled or pierced (punched). During puncture on the edges of holes there will often be formed cracks, dents, chipping of metal and other defects, which excludes the possibility of using this method for formation of holes under rivets, especially in thin-sheet frame constructions made from aluminum alloys.

With drilling the quality of holes is sufficiently high, therefore the given method is basically used in production of glued-riveted joints. For rivets up to 6 mm in diameter one should make holes with diameter 0.1 mm larger than diameter of rivet. According to standards effective in the USSR for making holes under aluminum rivets the drill should be selected with diameter 0.1-0.2 mm larger than the minimum diameter of rivet.

When drilling holes under rivets in the stack of parts with hardened glue layer under cutting conditions, the stability of the tool and quality of obtained holes very strongly affects the character of filler of glue composition. As experiments showed cement and quartz filler especially unfavorably affects these factos. Thus, during

manufacture of holes in a stack of sheets from alloy D16T (3 + 3; 4 + 4 mm) with drills (diameter 4, 5 and 6 mm) from alloy or high-speed steel at low cutting speeds the cutting edge of the tool was rapidly blunted, and in a number of cases inside the hole there was crumbled glue layer EPTs, VK 32-EM. At high cutting speeds (spindle of pneumatic drill ran up to 18,000 r/min) and with application of drills equipped with tips of hard alloy, the shown defects did not appear. There was observed increase of stability of hard-alloy drill approximately 10-20 times as compared to steel.

Study of the Possibility of Manufacture of Glued-Riveted Joints by Hot Riveting

Along with cold riveting, in industry in a considerable volume there is also used hot riveting, utilized for connection of different steel parts and other structural elements. Therefore, the study of the possibility of combining the process of hot riveting with gluing of metals, especially during manufacture of thin-sheet steel constructions, is of considerable practical and theoretical interest.

Analysis and generalization of literature and experimental data show that when cooling an intensely heated rivet, set in a stack of sheets, for example, from carbon steel (2 + 2 mm), the surrounding metal is heated quite rapidly (20-25 s), reaching a temperature of 500°C, then is slowly cooled. This circumstance causes prolonged heating (up to a temperature around 300°C) of basic metal near the rivet. The rivet, which cooling, is shortened in length and considerably presses the sheets, causing their plastic deformation.

Nonuniform heating of sheet between rivets with its plastic work for rivets causes loss of stability of the sheet because of intense development of tensile forces in the boundary fibers. Such phenomenon excludes close contact of mating parts and the formation of required pressures on the blue layer (in case of riveting on glue).

Increase of temperature considerably reduces the duration of polymerization of glue. However, most thermosetting glues, polymerizing

at high temperatures, requires considerable press-fitting pressures (6-20 kg/cm^2) [11, 14]. With usual gluing the glue layer is pressed with the help of complex devices with close contact of mating surfaces. Use of rivets for creation of the required pressures is possibly with their very frequent distribution, which is unsound: presence of a large number of holes weakens the section, excludes airtightness, and insignificantly increases the overall strength of the joint.

In accordance with the above it was possible to assume that the most promising glues for production of combined joints by the hot riveting method from the point of view of high heat resistance and technology of polymerization are domestic glues VS 10T, VS 350 and VK 7 and foreign glue Hidax 967 (England), consisting of phenolic resin and polyamides. Gluing with this glue is carried out at a temperature of 220-230°C under 1.4 kg/cm^2 for 2 min. Connections on glue Hidax 967 preserve very high strength when heating up to temperature 150°C (Table 94). However, conducted testing of glues VK 7, VS 10T and VS 350 under conditions of hot riveting of samples from carbon structural steel (stack 2 + 2 mm) did not give positive results. When setting hot rivets on freshly applied glue there is observed intense burning out of the glue layer in the cavity of the joint, especially near rivets, and also the formation of severe porosity and slag inclusions in the glue layer after its hardening. In case of setting rivets on a glued joint made earlier with hardened glue seam the sharp and rapid heating of the glue layer leads to its embrittlement, loss of strength and airtightness. Analogous phenomena also take place in the case of carrying out hot riveting of joints with application of glue Hidax 967.

Table 94. Shear strength τ_B in kg/cm^2 of Duralumin joints on glue Hidax 967.

Conditions of hardening		Test temperature in °C	τ_B
Temperature in °C	Time in s		
230°	120	20	350
230°	120	150	230

The most widely spread heat-resistant domestic and foreign glue compositions, composed on the basis of epoxy resins, also cannot be used for production of glued-riveted joints made by hot riveting, since they allow heating up to a temperature of 150-200°C [11, 14]. Only the addition of pyromellitic anhydride to these glues somewhat increases the heat resistance of epoxy compound, allowing heating to a temperature of 260°C. With increase of the polymerization temperature of glue (resin Araldite of type V) its shrinkage noticeably increases:

Temperature of polymerization in °C...............	100	120	140	160	180	200
Shrinkage in %.............	0,5+0.8	1+1,2	1.3+2	1,9–2	2+2.2	2,2+2.3

High heat-resistant glues VK 2, VK 6 and VK 8, although able to work at temperatures over 300°C, require high specific pressures during hardening and do not ensure stable filling of clearances in the cavity of the joint. Glued-riveted joints, made by hot riveting (with optimum spacing of rivets), on freshly applied glue (VK 2, VK 6 and VK 8) and then hardened (second method), with respect to strength indices scarcely differ from usual riveted joints. Due to nonuniform reduction the sections of the glue layer directly adjacent to the rivet turn out to be under great pressure, which ensures sufficiently high strength for the joint near rivets. Zones of the glue layer, far from the rivet, turn out to be insufficiently glued, in connection with which at these places the joint possesses lowered strength. Furthermore, the shown connections because of pores and cracks in the glue layer did not possess airtightness.

Making glued-riveted joints by means of hot riveting on hardened glue layer VK 2, VK 6 or VK 8 (first method) also turned out to be irrational. As a result of sharp and rapid heating the hardened glue layer is embrittled. Along with this, plastic deformation of base metal for the rivet and damping of rivets sheets from tensile forces of heat transfer leads to cracking and partial destruction of the brittle glue layer. This contributes the lowering of the strength of joints and disturbs their airtightness.

Most constructional domestic and foreign self-setting glues, technology of gluing with which allows the application of low specific pressures (on the order of 0.5 1 kg/cm^2), not able to withstand the thermal loads of hot riveting, since their heat resistance is only 60-100°C. The new recently created self-setting heat-resistant glue VK 9 also turned out to be unsuitable for this purpose. At temperatures around 350°C the glue starts to become brittle and loses efficiency.

Thus, the conducted investigations showed that not one of the existing constructional glues can be used for production of glued-riveted joints by means of hot riveting either because of their insufficient thermal stability and manufacturability, or due to severe embrittlement and cracking at elevated temperatures. For solution of this problem there are necessary search and development of new glue compositions, not only possessing high thermal stability and manufacturability, but also preserving sufficient elasticity and adhesive properties at temperatures 600-700°C.

Defects in Glued-Riveted Joints

During manufacture of glued-riveted joints in constructions from aluminum alloys there can appear different defects, basic of which are the following:

1) flattening of the rivet body between the riveted parts from their loose fitting, which leads to the formation of a reduced snap head and still greater increase of looseness of fit of the joinable parts, due to which the specific press-fitting pressure on the glue is severely reduced, there appear nonglued areas, defects in the glued seam (local increases of thickness, blobs), concentration of stresses in it, etc.;

2) misalignment of snap and set heads of the rivet, causing additional internal stresses in the glued seam, which subsequently lower its efficiency;

3) loose fitting of snap and set heads of the rivet to the surface of joinable parts, lowering the specific press-fitting pressure on the glue layer; this is caused by the presence of burrs and other roughness, on edges of the hole under the rivet;

4) misalignment of holes in parts of the riveted stack causing deformation (bending) of rivet body, due to which there appear considerable bluging forces;

5) unnecessary local deformation of riveted parts because of their excessive tightening by set head of the rivet, leading to squeezing out of glue in the zone of the hole under the rivet and thereby lowering the strength and airtightness of the glued-riveted joint;

6) diameter of rivet is somewhat smaller than diameter of the hole; in this case the rivet body is bent in the hole, which leads to the formation of reduced snap head, damage of hardened glue layer or lowering of specific press-fitting pressure on the damp glue layer;

7) incorrectly selected length of rivet, causing deformation of its body, shift of riveted parts, etc.;

8) appearance of "flakes" as a result of incorrect selection of set or bucker for riveting; this causes the formation of nonglued areas when riveting on liquid, paste-like or film glue, worsens streamlining of construction.

CHAPTER VI

MANUFACTURE OF GLUED-THREADED JOINTS

Threaded Joints

Threaded joints find the widest application in machine building. They are related to detachable joints and are made with the aid of bolts, screws, pins and nuts. Threaded joints are divided into unstressed and stressed. Unstressed – this is a joint without prestressing; in the absence of applied load there are no stresses in the components of such joints. Field of application of unstressed threaded joints is extremely limited. Stressed – these are joints with prestressing. In components of such joints by tightening there is created a stressed state even before the application of external load. Stressed threaded joints are the most widely spread. They are applied both with static and dynamic loads.

Along with threaded joints, made with usual screws and bolts, in recent years in the automotive, motor and tractor, ship-building, aircraft-building and other branches of technology new threaded joints, made with self-tapping screws, found application [15, 20, 35]. In conformity with the method of thread forming, self-tapping screws are manufactured for thread rolling (in components from plastic materials) and cutting (in components from brittle materials) (Figs. 61-63).

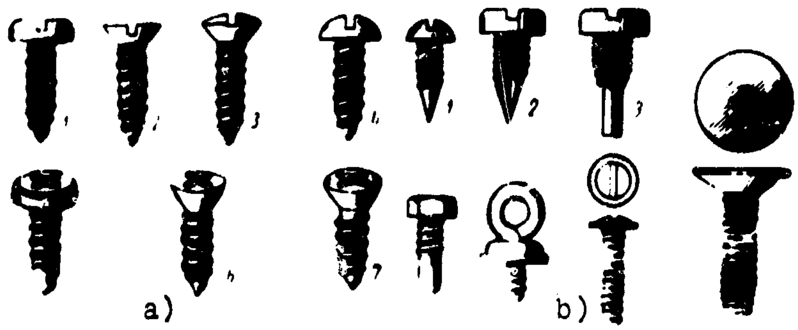


Fig. 61. Self-tapping screws: a) German production; b) English production.

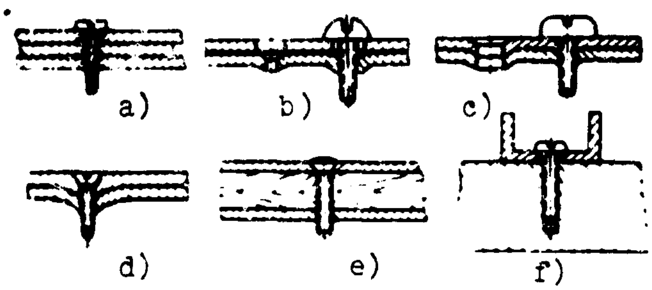


Fig. 62. Types of mating of parts with the help of self-tapping screws.

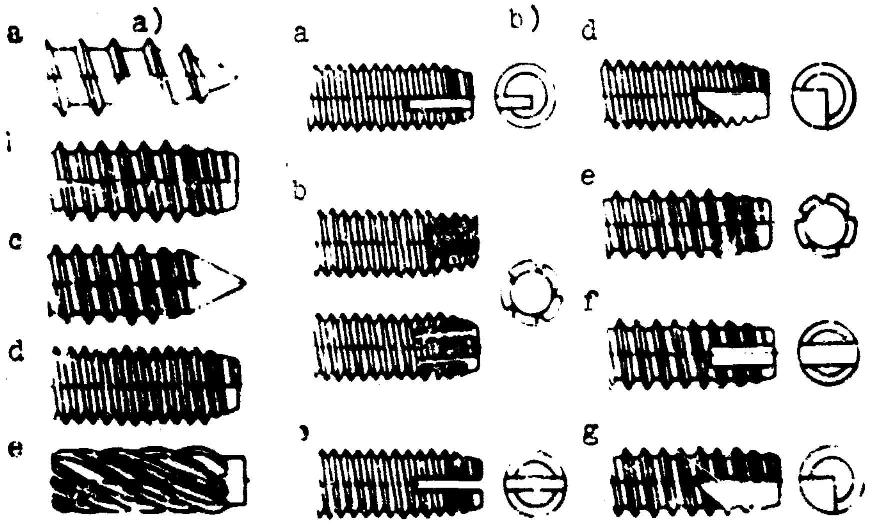


Fig. 63. Self-tapping screws of American production: a) for thread rolling; b) for thread cutting.

The body for the majority of self-tapping screws, in contrast to usual screws, consists of a section with full special profile thread, (threaded) chamfer, having 4° angle, and guide shank. For convenience of cutting (rolling) thread with a screw, in its guide part there is stripped a cone (Fig. 61). Size of head for screws is connected with diameter of the body and dimensions of slot.

For certain types of screws the formation of lips and removal of excess metal, (in the form of chips, filings and so forth) along the entire length of body of the screw is provided by several rectangular grooves, which assure gathering of chips when screwing a self-tapping screw into a blank hole when making screwed and glued-threaded joints from heterogeneous materials. According to standards there are manufactured scre' with six longitudinal grooves, arranged spirally along the body of screw. Depth of grooves is equal to half the difference of diameters of outside and inside thread, width corresponds to 1.2 of the depth (for screws up to 6 mm in diameter). In foreign self-tapping screws the depth of grooves differs from those screws turned out in USSR and has a somewhat larger value. Thread pitch of screws turned out in the USSR also differs from foreign and is 1.0-1.75 mm (depending upon external diameter of screw and thickness of joinable parts).

Self-tapping screws are manufactured, as a rule, with rouned thread head with radius 0.05-0.1 mm (depending upon pitch of thread). This is caused by complexity of formation of acute angle during the manufacture of thread by rolling method. Furthermore, acute gle would cause damage and breaking-off of the rolled thread.

Abroad [20] there are manufactured general-purpose self-tapping screws with different fillister head: 1 - cylinder; 2 and 3 - for flush connection of parts; 4 - with button head; 5, 6 and 7 - with phillips head (Fig. 61a) and special-purpose; 1 and 2 - rolling thread and forming holes; 3 - cutting thread in preliminarily made holes; 4 - with oval rod, without slot; 5 - equipped with ring; 6 - with countersunk head and longitudinal slot; 7 - with countersunk phillips head (Fig. 61b). They will cut thread.

In the United States [35] there are manufactured self-tapping screws, for rolling (Fig. 63a) and cutting (Fig. 63b) thread. They have different heads, analogous to those shown on Fig. 61a. These screws are subdivided into five types.

Screws of type A are intended for highly durable constructions (Fig. 63a). With these screws there are joined parts from thin-sheet metal (steel, aluminum alloys) or from easily deformable plastics. In the parts there is preliminarily made a hole of somewhat smaller diameter than the outside diameter of the screw. The body of the screw in the chamfer and guide part is equipped with thread of very large pitch (with respect to type of bit), and the guide part is finished with a cone.

Type B screws are equipped with thread with large pitch, and the guide part is made in the form of a truncated cone. They are designed for joining parts from plate metal. In the parts there is preliminarily made a hole of somewhat smaller diameter than the screw diameter.

Type C screws by the character of thread and application are analogous to type B screws, but in contrast to the latter they have a conical guide part.

Type D screws are equipped with standard metric or inch thread, and the guide part is made in the form of a truncated cone. It is recommended to join parts working during vibration loads with these screws.

Type E screws have special helical heat-treated thread, making it possible to preliminarily partially hammer them into the hole of a part, and then to roll thread. They are also used for joining parts working during vibration loads.

Screws, cutting thread (Fig. 63b), are equipped with longitudinal grooves along the guide part of the screw for collection of chips and easing of boring holes. The latter is carried out by sharp lips,

on edges of grooves. These screws are divided into two groups. One group, including types A, B, C and D is equipped with standard screw thread (metric or inch); the other has thread profile with increased pitch. Type A screws are equipped with a single narrow groove along the body. They are intended basically for joining plastic metals and plastics, can also be used for joining a number of brittle materials (cast iron and so forth). They provide restoration of partially preserved thread.

Type B screws are turned out in two versions: with thread to the end of guide part and with thread only to chamfer. They are used for connection of parts from very durable materials, working under the influence of vibration loads.

Type C screws have a single groove, passing along the diameter of guide part. Their application is analogous to type A.

During the manufacture of type D screws by the milling cutter we select the sector of metal from the area of section of guide part with the formation of a wide groove, ensuring distribution of a large quantity of chips during thread cutting. Their application is analogous to that of type A screws.

Type E screws have thread of large pitch in the chamfer, and also five grooves for collection of chips with five lips for thread cutting. It is recommended to use them for joining stamped metallic parts and brittle plastics. Numerous cutting edges and recesses provide very qualitative thread cutting and exclude the removal of excess material.

Type F screws are equipped with thread of large pitch and a wide groove, milled along the diameter of base of truncated cone of the body. They are used for joining parts from plastic and brittle materials, where a qualitative thread is not required.

Type G screws are analogous to type D. They are equipped with thread of large pitch in the chamfer. Groove for collection of chips is selected also by milling cutter along the sector. Separated screw pitch provides shearing of the necessary quantity of material during thread cutting. Deep recess, occupying a quarter of the base in area, is as if a bin for collection of twisted shavings. Their application is analogous to that of type F screws.

Self-tapping screws thanks to rolling or cutting of thread in the process of advancing ensure tight connection of parts. In this case the walls of holes are packed and are strengthened.

The best packing of walls of holes is created during thread rolling (i.e., without cutting of shavings). Formation of thread by self-tapping screws by the rolling method found application in constructions made from plastics, steel, aluminum alloys and so forth. However, self-tapping screws are useless for connection of parts from brittle materials of cast iron, certain type of structural plastics (ebonite, bakelite) and so forth. In this case it is required to preliminarily cut thread (partially) in the hole.

Connection of parts with the help of self-tapping screws is especially rational to use in constructions and articles having one-sided approach. However, to ensure rated strength of the joint there is required arrangement of self-tapping screws with very small pitch, which is undesirable, expecially when connecting thin-sheet parts (thickness 1-2 mm) of great length. Therefore, it is necessary to drill a large number of holes, reducing the section of mating parts. Furthermore, moisture getting into overlap causes areas of corrosion.

Joints based on self-tapping screws do not provide airtightness of the fastened elements of constructions. This phenomenon is worsened with preliminary drilling of holes and subsequent assembly of a stack, since noncoincidence of holes leads to the formation of loose joints, lowering the vibration strength of the article. There

is required preliminary fixing of the parts and drilling of holes in an assembled stack (productivity of labor is lowered), there appears waviness ("flakes"), although to a smaller degree than in riveted joints. The large amount of screws necessary to ensure the specified strength of the joint makes the article heavier. Installation of countersunk screws leads to weakening of the section of parts and reduction of airtightness of joints.

Joining of parts from aluminum alloys of various brands, not preliminarily protected from corrosion, with the help of self-tapping screws, leads to the formation of electrochemical corrosion if moisture gets into the cavity of the joint. The described deficiencies of screw joints to a considerable extent pertain to bolt joints.

Glued-Threaded Joints

Recently in domestic and foreign technology a combined (more progressive) type of connection of parts — glued-threaded, carried out with usual and special screws, bolts and gluing of metals and nonmetals, has started to find increasingly wider application. In this case the advantages of screw, bolt joints and gluing are used to the maximum and many deficiencies inherent to each of these joints separately are excluded.

Combined glued-threaded joints are favorably compared with usual threaded. Thus, they possess higher efficiency (Table 89), especially with dynamic repeated-variable loads, and also are hermetic, lighter (as compared to standard threaded) and fire-proof (as compared to glued). In these joints the glue layer, monolithically fastening the mating parts along the entire area of overlap, absorbs shear forces, excludes the formation of waviness (when mating thin-sheet elements), protects inner surfaces of parts from corrosion, ensures airtightness of the joint, and also locks bolts and screws. The bolts and screws absorb normal forces directed perpendicular to the glued seam, bending moments and eliminate the necessity of application of bulky pressing devices for creation of specific pressures on the glue layer.

Glued-bolt joints are especially effective when joining plate strong metallic constructions of steel, aluminum alloys, and when joining metallic parts with nonmetallic.

Glued-screw joints are rationally used for structural elements, having one-sided approach, when joining articles in a consolidated assembly, during assembly, for creation of permanent joints, when joining metallic parts with elements from nonmetallic materials (plastics, wood and so forth).

Use of glued-screw joints in constructions permits decreasing the amount of screws (bolts) in the seam, which lightens the article, excludes the possibility of loss of stability of thin sheet linings, made from material possessing relatively low elastic modulus (aluminum alloys and others) and small rigidity (annealed aluminum alloys and others).

Use of glued-bolt joints permits lowering the expenditure of materials on bolts (in connection with decrease of their quantity), eliminating the application of assembly welding and creating hermetic seams, preventing the formation of intralap corrosion.

Technology of Manufacture. Areas of Application

Glued-threaded joints in constructions can be made by three methods: 1) with installation of bolts or screws through earlier glued parts with completely hardened glued seam; 2) installation of bolts or screws through nonhardened liquid glue or glue film applied earlier on the mating surfaces with their subsequent hardening already in the combined joint; 3) introduction of liquid glue into the cavity of overlap after installation of bolts or screws with its subsequent hardening in the combined joint.

Method 1 provides more uniform forming of glue seam in the joint and excludes the possibility of formation of nonglued areas, promotes production of combined joints with higher and more stable strength. In this case the glued-threaded joints are made by the

following flow diagram. Parts are degreased, chemically or mechanically treated prior to gluing; after this on the mating surfaces there is applied liquid or paste-like glue, parts are assembled, fixed and glued by the usual method under conditions corresponding to the given glue Then in the parts there are drilled holes and bolts are installed or self-tapping screws are screwed in. In case of installation of usual screws in holes we preliminarily cut the thread. A deficiency of this method is the possibility of damage to glue layer during formation of holes and cutting (or rolling) the thread.

For the manufacture of glued-threaded joints by method 1 it is possible to use thermosetting and self-setting liquid, paste-like and film glues. The working character of the screw during its installation into the hole with hardened glue layer very strongly affects the type of filler in the glue composition. Thus, the presence of mineral filler (quartz and porcelain dust, cement and others) considerably hampers tightening of screws, especially usual (with sharp crest of thread), as a result of which there appears danger of damage to the glue layer and thread in the chamfer of the screw. Self-tapping screws give the best results. Selection of the type of glue also very much depends on the design features and overall dimensions of the article.

Method 2 is simpler and more technological, inasmuch as it does not require special attachments and bulky equipment for pressing of glue. Pressure on the glue layer in its hardening process is created by bolts or screws themselves, installed through liquid or unhardened film glue. However, in this case, as during riveting, a glue layer of nonuniform thickness is inevitably formed; in separate places there can appear nonglued areas, especially when joining parts with thickness less than 1.5 mm. For decrease of the danger of appearances of nonglued areas it is necessary to try to apply glue with as even a layer as possible 0.6-0.7 mm thick.

Manufacture of glued-threaded joints by method 2 is recommended in the following sequence: layout of parts; drilling of holes under bolts, screws (when necessary also countersink); chemical treatment

or machining of mating surfaces prior to gluing; control (preliminary) assembly of parts and clamping, then their disassembling; application of glue on mating surfaces; final assembly of unit and installation of bolts or screws. In a number of cases it is possible to use another flow diagram: degreasing of parts, drilling of holes only for clamping of parts, preparation prior to gluing, application of glue, assembly of unit, clamping of its elements, drilling of holes under bolts or screws and installation of bolts or tightening of screws.

For the manufacture of glued-threaded joints by method 2 it is possible to use thermosetting and self-setting glues, not requiring creations of high pressures of molding during their hardening.

Essence of method 3 and its technology are described in Chapter III. In this case it is possible to use only glues possessing high penetrating power.

To ensure more reliable airtightness of joints, especially those made by method 1, and also locking of bolts and screws it is recommended to dip them in glue before installation in the hole.

Glued-bolt joints were used for the first time during construction of bridges [21, 33, 36, 34]. Their introduction was preceded by many research works, in the course of which there was studied the influence of technological and operational factors on the properties of joints, and there were also tested different glues and technologies of their use. Self-setting glue based on unsaturated polyester resins with vinyl compounds of Vestopal LT turned out to be very rational. For acceleration of polymerization into the glue composition there is introduced catalyst, accelerator, changing the adhesive working life of glue depending upon percentage content (from 10 min to several hours at usual temperature) and thereby affecting the technology of manufacture of glued-bolt joints.

Strength of joints using Vestopal LT grows comparatively rapidly. Thus, 2 h after its application it reaches 65%, after 4 h 90%, after 10 h 100%. Shear strength of lap glued steel samples 1-2 mm thick is 300-350 kg/cm^2, 4 mm thick 200-400 kg/cm^2 (depending upon the state of surface). Cleaning of glued surfaces by sandblasting gives good results. Glue is able to work in the range of temperatures from -30 to +80°C. With its use in glued-bolt joints the permissible stress of glued joints was taken as 60 kg/cm^2.

Introduction of Vestopal LT into glue composition as aluminum oxide filler noticeably improves its physical and mechanical properties. Thus, the shear strength and density of the glued seam are considerably increased, shrinkage stresses are lowered, and the glue becomes more technological and economical.

For checking the efficiency of glued-bolt joints, made with vestopal glue, we shear tested steel samples under different conditions (Fig. 64). Bolts (standard) 12 mm in diameter were inserted into a hole 13 mm in diameter on freshly applied liquid glue. Surface of the samples was sandblasted. Dimensions of samples were accepted from calculation of failure on the glue seam at short-duration strength of the glued joint, equal to 120 kg/cm^2, with stresses in steel not exceeding the elastic limit. As a rule, we took the thickness of cover plates equal to more than half the base plate of the sample. Results of comparative tests are shown on Figs. 65, 66 and in Table 95. Analysis of results of tests shows that, in contrast to purely glued joints, strength when working on static shear of constructively analogous glued-bolt joints depends little on the length of cover plates (Fig. 66). Glued-bolt joints considerably exceed purely bolt joints in shearing strength (Fig. 65). As can be seen from Fig. 65, load-shear diagram for glued-bolt joints sharply differs from the diagram for purely bolt joints.

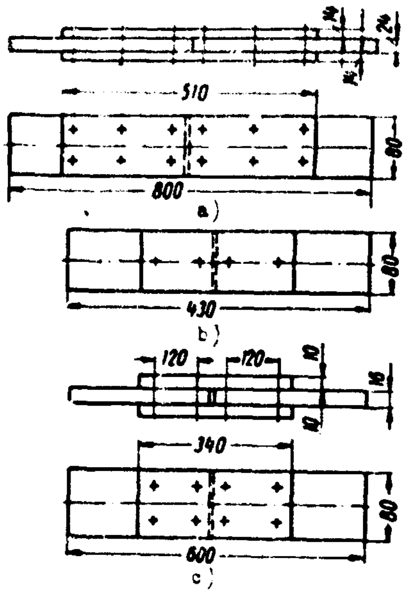


Fig. 64. Glued-bolted samples: a) with three-row seam; b and c) with two-row seam.

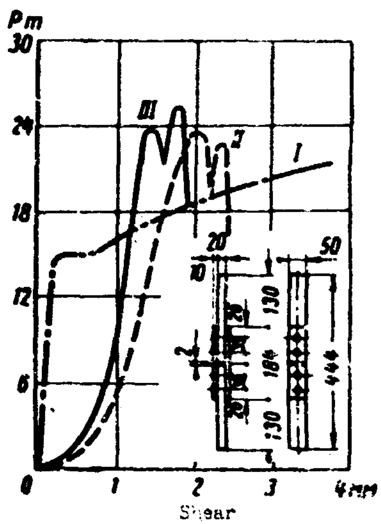


Fig. 65. "Load-shear" diagram, obtained during tensile test of samples of bolt (I), glued-bolt with standard bolts (II) and glued-bolt with highly durable bolts (III).

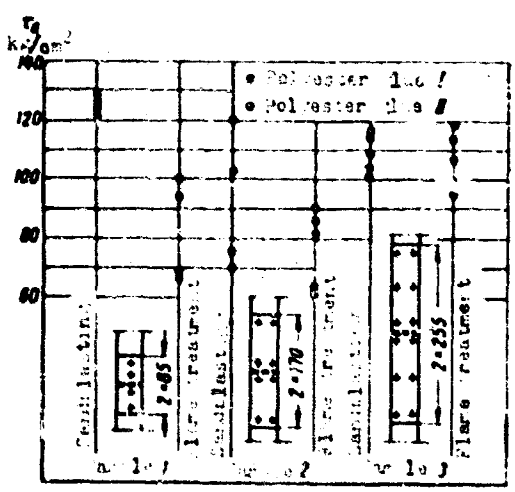


Fig. 66. Dependence of strength of glued-bolt joints on the length of cover plate and surface treatment.

Table 95. Shear strength of double-shear samples (glue Vestopal LT) at different temperatures.

Alternating of holding of samples at different temperatures (25 cycles)	−20 °C 4 h, +20 °C 2 h		+80 °C 12 h, +20 °C 12 h		−20 °C 4 h, +80 °C 4 h
Temperature of tests	+20 °C	−15 °C	+20 °C	+80 °C	+20 °C
τ_s in kg/cm^2	139—152	146—155	160—147	156—144	132—129—122

The strength of joints made on Vestopal glue is not affected by different temperature conditions (within limits from -20 to +80°C).

For the purpose of studying the effect of atmospheric influences (sun, rain, snow and so forth) on the rupture strength of glued-bolt joints the samples (Fig. 64) were shear tested for two years through specific time intervals (28, 111, 255, 365 and 730 days). In all cases the breaking load of glued-bolt joints was 34,000-38,000 kg, i.e., exceeded the yield point of the steel used (2800-3000 kg/cm^2). During inspection of ruptured samples after biennial atmospheric influences there was not revealed what changes and corrosion damages of metal were in the zone of bolts and between them. As a rule, failure of the glue layer carried an adhesional character, i.e., flowed on metal-glue boundary.

Data obtained as a result of the described investigations served as the basis for designing glued-bolted structural elements of a bridge with application of Vestopal LT glue.

Rated shear strength of glued joints for determination of length of junction plates and cover plates was accepted equal to 60 kg/cm^2.

Glued joints with respect to diagram of transmission of forces work analogous to highly durable bolts. Therefore, to ensure operation of bolts in a combined joint according to the principle of highly

durable bolts during the manufacture of couplings of the strut lattice of a bridge the holes under bolts were drilled somewhat larger than the bolt diameter (for example, for bolts 12 mm in diameter the hole was made 13 mm in diameter), which ensured transmission of shears with the help of glue layer; in this case the bolts joined the work only after its failure.

For perception of tearing forces (tear), and also in case of an accident along the edges of junction plates there were installed M20 bolts for bracing struts and M16 for braces. Compressing forces of bolts increased the resistance to slip. Coupling of junction elements of a bridge with help of bolt joints was carried out according to the following flow diagram. The surface of elements to be coupled was sandblasted, liquid glue Vestopal was applied, struts and braces were placed between junction plates, with nonhardening glue the bolts were inserted and tightened. By tightening the bolts the required pressure was created on the glue layer, which permitted excluding the application of special pressing devices. Glue was hardened at 17-20°C. With uniform application of glue the thickness of glue layer in glued-bolt joint varied from 0.5 to 0.8 mm.

Inasmuch as works on erecting the bridge with glued-bolt joints were conducted during bad weather, with a relatively low plus temperature, separate critical nodes of the strut lattice were subjected to heating by torches for acceleration of polymerization of the glue composition.

Investigations conducted in the process of utilization of the bridge, and comparison of three types of joints - riveted, bolt (highly durable bolts) and glued (when τ_B = 60 kg/cm^2) permitted making the conclusion that when designing glued bridges, taking into account the work of only the glued joints, the surface of joinable elements should be increased 2-3.5 times, or the tensile strength of glue should be increased to 250 kg/cm^2 (Table 96).

Table 96. Comparison of permissible stresses of different types of joints of structural steels in kg/cm^2.

Steel	Joint				
	Rivet		Bolt		
	Basic load	Basic and additional load	Basic load	Basic and additional load	Glued
St37	122	140	125	412	60
St52	183	210	170	190	60

Experiments showed that the adhesion strength of glue and the quality of glued-bolt joints depends on the thickness of glue layer and uniformity of its application. The thinner and more uniform the film based on unsaturated polyester resins, the better and higher the quality and strength the combined joint will have. Strength of glued seams in glued-bolt joint was not lowered during testing in different media and at lowered temperatures. The danger of appearance of cracks appeared at a temperature lower than -30°C. Noticeable lowering of strength of the glue layer occurred at a temperature higher than +100°C.

On separate junction plates of the strut lattice of the bridge during the formation of glued-bolt joints we applied a glue composition 0.2-0.6 mm thick. Time of hardening was around 60 minutes.

Subsequent works made possible in 1963 the erection of a steel bridge with 58 m span in the city of Marle with prestressed glued constructions. Every structural prestressed node was glued and pressed by the force of highly durable bolts. For perception of forces in nodes (218 t) with allowable load on the glued seam 100 kg/cm^2 there were provided 25 highly durable bolts. In the glue composition the base was polyester resin, and filler – aluminum oxide.

Glued-threaded joints are also used in the construction industry during the manufacture of aluminum bindings and stained glass [25].

The most complex node during the manufacture of metallic bindings is mating of corner elements, which is usually carried out by various methods: bolts. welding and so forth. However, all these traditional methods of fastening do not correspond to requirements of airtightness and economic effectiveness. Welding causes warping and buckling of aluminum profiles. For the purpose of reduction of warping and creation of hermetic nodes, glued-bolt joints were used during their manufacture.

For the manufacture of aluminum bindings and stained glass with glued-screw joints there are developed special profiles (Fig. 67), into nodal couplings of which there are introduced press-fitted parts, ensuring construction of glued joints. For necessary press fitting there are provided adjusting screws, making it possible to create the necessary pressure of the glued seam. Basic forces in nodal couplings of bindings are absorbed by glued joints, and the screws serve as additional bracings, contribute to ease of assembly of parts of bindings and play the role of press-fitting devices. Glued seam ensures airtightness of couplings absorbs shear force at nodal attachments and increases their rigidity. The presence of glued joints permits subjecting the nodes of bindings to anticorrosive coatings (anodizing and so forth).

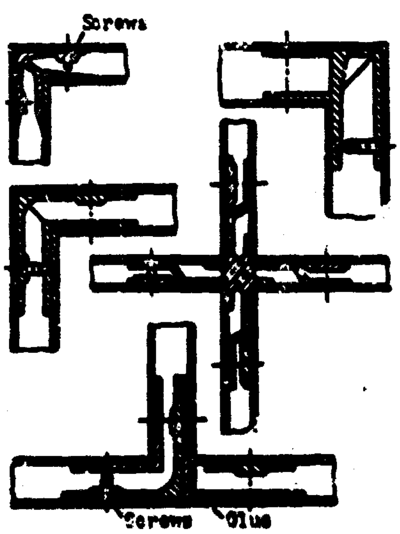


Fig. 67. Nodal glued-screw couplings of elements of aluminum bindings and stained glass.

High strength is provided by thermosetting glues, however the necessity of heat treatment with heating up to a temperature of 180°C and above excludes their application in glued-screw joints of bindings and stained glass since this is economically unsuitable and it is very complicated to place large-sized articles in a heating furnace. Therefore, there was used a two-component self-setting glue composition agomet E, possessing high resistance to the influence of various media. Shear strength of gluing of aluminum alloys is 100-200 kg/cm^2. The given glue is hardened at a temperature of 18-20°C and has adhesive working life 30-60 minutes. Elements of bindings before putting on the glue are thoroughly degreased in a solution of carbon tetrachloride or trichlorethylene. Glue is applied with a brush.

During comparative shear tests of samples of nodal couplings of aluminum bindings the following results were obtained:

Method of connection........................	Bolt	Welded	Glued-screw (agomet glue)
Breaking load in kg.........................	546	1894	3460

Application of glued-screw joints in a sash gives the following advantages: lowers the cost of manufacture; does not require additional machining and expenditure of material on cover plates and so forth; eliminates the application of additonal equipment for molding the glue layer.

For obtaining effective strength when coupling the components of the shell of a warhead the ordinance arsenal (the United States) used glued-screw joints (screws are countersunk for obtaining a smooth airfoil) [42]. The shell of the warhead has a forward section (steel cylinder) and aft part (aluminum cylinder).

In technology there are also used special glued-screw joints, made on the basis of fastening with one-sided approach (Fig. 68). Such joints permit mating not only metallic parts, but also a totality

of metallic and nonmetallic elements in one stack. In a preglued stack of two parts 1 (Fig. 68a) there is made a corresponding hole, into which there is inserted bushing 2 with female thread, made from plastic metal. Then glue is applied on the external surface of the ready stack of parts 1, mating part 3 is placed on it and with a standard screw, inserted into the bushing, is tightened to the shown stack 1. Thanks to deformation of the bushing there is ensured a tight and durable connection.

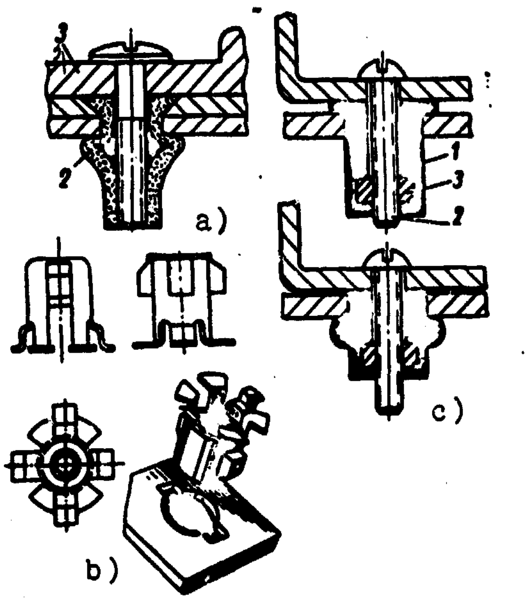


Fig. 68. Glued-screw couplings of parts by attachment with one-sided approach: a) connection with a metallic bushing and standard screw; b) with bolt-bushing (bayonet) with tongues; c) with bush and standard screw.

On Fig. 68b is shown a special bolt-bushing bayonet with tongues, developed and utilized by the firm S. A. Champion [23] for one-sided attachment. The bolt is inserted in the hole with notch diagonally. By rotation of bolt 90° there is attained tightness of connection of parts thanks to pressing of tongues. With the presence of a glue layer there will be formed a permanent hermetic joint, press-fitted by force of bayonet bolt. Internal cavity of the bushing is equipped with thread, allowing advancement of the screw for connection of additional structural elements.

The English firm Raviplug Co. [23] supplies a fastener under the name of Ravinut. Coupling of parts with this fastener is produced in the following way. In the lower part (Fig. 68c) a hole is drilled, in

which we place a rubber bush 1 with a nut 3 built into it. The bush is finished by a flange. Into the bush is inserted bolt 2. When tightening the bolt the nut, being turned on the bolt, presses the bush, forming a roller, durably connecting the mating parts. Presence of a glue layer ensures airtightness of the joint and protects the internal surfaces of the parts from corrosion.

One-sided attachment [23], shown in Fig. 69a and b, is also of considerable interest. The fastener silentblock (Fig. 69) consists of a bolt with nut 1 and bushing with female metric thread. Shank of the bolt is made in the form of a turned metallic plate 2, on which there is put a spring, equipped on the end with a pin 3. Plate with pin is introduced into the hole, after which the nut is fully screwed on the free end of the bolt, tightly pressing the bushing to the mating parts. This attachment permits fast fixing of sheets also during the formation glued-riveted joints on liquid glue, eliminating shift of parts in the process of making subsequent holes. The fastener is manufactured by English industry for 2.4, 3.2, 4 and 4.8 mm holes.

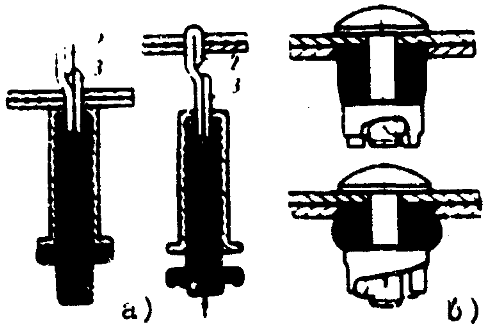


Fig. 69. Joining of parts with device: a) silentblock; b) silentblock-vibrex.

Fastener silentblock-vibrex includes a bolt with a wide lentil head and screw slot, rubber bushing, cam sleeve, in which the transverse pin moves. For installation of this fastener first the bolt is inserted in a hole 5.5 mm in diameter. Then on the free end of the bolt there is mounted the rubber bushing and cam sleeve. Into the body of the bolt there is inserted the transverse pin, ensuring arrangement of the rubber bushing in the most extreme position. The assembled fastener with upper sheet is introduced into the second sheet to be mated having a hole 12.5 mm. By rotation of the bolt the

transverse pin moves to its extreme upper position and, by pressing the rubber bushing, will form a durable and tight joint.

Besides the given examples, glued-threaded joints also started to find wide application in automobile and motor and tractor manufacture, railroad car and farming machine construction, ship and aircraft manufacture and so forth. It is especially profitable to use them for joining metallic parts of complex configuration, thin-walled – with very thick-walled, metallic – with nonmetallic, steel – with cast-iron, etc., where it is impossible to use riveting or welding.

In a number of cases, especially where only one-sided approach is possible to the stack of parts to be joined, it is very rational to make glued-threaded joints with self-tapping screws (Figs. 61 and 63). Thanks to the rounded crest of the thread these screws provide more durable and tighter glued-screw joints in steel and aluminum articles than standard screws, having sharp crest of the thread.

During development of the technology of manufacture of glued-threaded joints with the application of self-tapping screws it is necessary to consider not only the design features of these screws, but also the character of their effect on the glued seam.

For simultaneous connection of three metallic already glued in a stack (Fig. 62a) it is recommended to use cylindrical self-tapping screws, shown on Fig. 61a. In the upper part (on the side of the head) there is preliminarily drilled a hole with somewhat larger diameter than the screw diameter (for its free passage), and in the remaining parts – somewhat smaller. In the latter the thread is cut with a screw. In this case the screws can be placed through freshly applied glue, but before making the holes it is necessary to thoroughly fix the parts.

Button head screws (Fig. 61a – 1) can be advanced into the lower part without the presence of a hole in it, by pressing it tightly to the upper part. For this in the upper part there is drilled a hole with somewhat larger diameter than the diameter of the body of

the screw. Into the hole the screw is inserted, the lower part is punched by it and the screw is advanced into it. Thus, it is possible to make qualitative glued-screw joints only by method 2. In case of the presence of a hardened glue layer in the joint when advancing the screw it is damaged due to unbending of the lower part (Fig. 62b). In avoidance of this in the lower part it is expedient to preliminarily drill a hole of considerably smaller diameter than the diameter of body of the screw (Fig. 62b).

Cylindrical self-tapping screws with guide part in the form of a truncated cone (Fig. 61b – 2, 3) are recommended for joining two parts only with holes preliminarily made in them with smaller diameter than the screw body (Fig. 62c). In this case the hardened glue layer can be damaged because of unbending of the lower part. Therefore it is more rational to install these screws on freshly applied glue.

Screws with countersunk and fillister heads (Fig. 61a – 2, 3, 6, 7) can be used for joining metallic parts without preliminary drilling of holes in them. For this the upper part is pierced with a screw, and then it is advanced, rolling thread simultaneously in the two mating parts (Fig. 62d). With this there occurs simultaneous local crumpling of the two mating parts under the screw, eliminating their relative displacement, since the pinches enter each other. It is possible to install the shown screws in such a way only on freshly applied liquid or paste-like glue.

On Figure 62e, f there are shown examples of joining metal with wood and other nonmetallic materials with the help of self-tapping screws with fillister head (Fig. 61a – 3) and with cheese head (Fig. 61a – 1). In the metallic (upper) part there is preliminarily drilled a hole with somewhat larger diameter than the screw diameter, and in the remaining parts – somewhat smaller. In the latter the thread is rolled by self-tapping screw. In this case it is possible to manufacture glued-threaded joints by methods 1 and 2.

Glued-threaded joints with use of type A screws (Fig. 63a) can be successfully made only by method 2. Hardened glue layer is highly

damaged during tightening of this screw. With screws of type B, C, and D (Fig. 63a) it is possible to make glued-screw joints by methods 1 and 2.

Type E screws (Fig. 63a) can be placed only on freshly applied glue. The hardened glue layer is cracked when driving, then when tightening this screw. Screws ensure durable and tight joining of parts with thickness equal to the diameter of screw. With the screws shown on Fig. 63b it is possible to make glued-screw joints by methods 1 and 2. In this case the application of glues of considerable viscosity is even permissible (including mineral fillers – cement, quartz and so forth).

The quality of manufacture of glued-screw joints with use of self-tapping screws highly depends on the diameter of holes made under the screws. Diameter of the holes is designated depending upon the diameter and type of screw and joinable material in the stack. Unnecessary increase of hole diameter does not provide the required durable and tight connection of parts. With decrease of hole the force necessary for advancing the screw increases. There is a definite relationship between tensile force of screw N and torque $M_{\text{кр}}$.

Moment of friction forces in the thread of self-tapping screw is equal to

$$M_{\text{т}} = Nfr.$$

Moment necessary for creation of tension in the stack is equal to

$$M_{\text{н}} = Nr\,\text{tg}\,\alpha,$$

where N – tension (axial force) of stack by the screw; f – coefficient of friction along surface of thread of screw chamfer; r – average of screw radius thread; α – thread angle.

Thus, the necessary moment for tightening a self-tapping screw is equal to

$$M_{з} = M_{p} + M_{н} = N(fr + \mathrm{tg}\,\alpha r) = Nr(f + \mathrm{tg}\,\alpha).$$

Let us express this dependence of torque on tensile force of self-tapping screw through screw diameter d, having taken

$$r = c - \frac{d}{2},$$

where C – coefficient depending on the geometric dimensions of screw.

By converting the preceding equality, we obtain

$$M_{з} = N\frac{dc(f + \mathrm{tg}\,\alpha)}{2},$$

whence

$$N = \frac{2M_{з}}{dc(f + \mathrm{tg}\,\alpha)}.$$

From this formula it is clear that the relationship between torque and tensile force of glued-screw stack by self-tapping screw can be determined with known coefficient of friction f, appearing during rolling of thread in the process of tightening. When advancing the self-tapping screw into a smaller than nominal hole there appear damages of thin sheet metal and hardened glue layer. As a result of excessive deformation of sheet surface of the part at the holes will be formed secondary stresses in the glued seam and cracks in the metal.

A hole somewhat bigger than nominal leads to incomplete cutting of thread, not corresponding to standards and to a general lowering of strength and density of connection. When joining a stack of several sheets first (on the side of the screw head) it is recommended to drill a hole of somewhat larger diameter than for the screw, in subsequent parts of the stack somewhat smaller than for the screw.

When making glued-screw joints (with new glue) on an earlier glued stack of parts the diameter of the hole is determined experimentally. Thus, in the first batch of glued samples there were drilled holes 0.6 of the screw diameter, in the second batch 0.75 and in the third 0.8 of the screw diameter.

When advancing self-tapping screws into holes of samples of the first batch there was revealed damage of the glue layer and local destruction of thin (less than 1-1.5 mm) plates from D16M aluminum alloy. For tightening there was required considerable torque, which was not provided by reversible pneumatic screwdrive RPO-350 with the greatest torque 180 kg·cm, designed for tightening usual screws up to 12 mm in diameter. In our case the diameter of the accepted screws was 4 mm. Understated hole diameter hampered thread rolling in aluminum samples. This caused slanted advance of the screw with its severe swaying in the hole. Such a picture was observed when advancing self-tapping screws into holes of the second batch of samples, made from steel plates. Into holes of the second batch of samples from aluminum alloys it became possible to advance screws only through a layer of moist glue.

Inspection of samples from aluminum alloys with glued-screw joints, made on hardened glue, showed the presence of a damaged glue layer. On samples of the third batch installation of screws through a hardened glue layer into holes with diameter 0.8 of the screw diameter ensured very qualitative combined joints.

Thus, holes under self-tapping screws 3-5 mm in diameter should be $(0.8-0.82)d_B$, where d_B – diameter of screw. Length of self-tapping screws with their diameter within 3-5 mm should be larger than the thickness of the stack of parts to be joined by 5 mm. On the basis of foreign data [35] the torque for advancing self-tapping screws should not exceed 1/3 the torsion force of the screw.

Tool. For advancing self-tapping screws and tightening the nuts when joining thin-sheet parts we most frequently use the RPO-350

and RPO-800 type reversible pneumatic screwdriver, model D2-TR pneumatic torque nut runner and PV-800 pneumatic screwdriver.

Reversible pneumatic screwdrivers are more reliable, convenient, are less sensitive to overloads and lighter than electrical. They are used for assembly and installation operations. Basic specifications of certain widely used models of pneumatic screwdrivers and nut runners are listed in Table 97.

Table 97. Technical data of pneumatic screwdrivers and nut runners.

Pneumatic screwdriver	The greatest diameter of tightened screws and nuts in mm	Number of idling revolutions per minute	The greatest torque in kg·cm	The greatest power, in horsepower	Expenditure of compressed air at idling in m^3/min	Overall dimensions in mm	Weight, in kg
RPO-350	12	350	180	0.33	0.4	248×132	1.9
PRO-800	6	800	75	0.2	0.3	230×122	1.47
D2-TR	[illegible]	300	320	0.35	0.38	460×125	4.7
PV-800	6	800	80	—	0.3	—	1

Note: Air pressure in line 5 at.

Reversible pneumatic screwdrivers RPO-350 and RPO-800 are equipped by two heads: one of them has a torque indicator, providing adjustment of moments within limits of 20-70 kg·cm for screws up to 6 mm in diameter (RPO-350). Large-sized screws are screwed in without being torqued. Screwdrivers are supplied equipped with an interchangeable tool to accommodate different types and sizes of slotted screws and nuts. Tool is fastened in a spindle by a special lock.

Pneumatic torque nut runner D2-TR is equipped with torque indicator, ensuring adjustment of moments within limits of 40-320 kg·cm. Pneumatic screwdriver PV-800 is supplied with a head, which has a torque indicator, ensuring adjustment of moments within limits of 20-70 kg·cm. Screwdriver has an interchangeable tool to accommodate different types and sizes of screws and nuts. Tool is fastened in the spindle by a special lock.

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ABSTRACT (UNCL, 0) ABSTRACT OF REPORT. The book deals with a new progressive method for joining of structural aluminum alloy elements production of composite, permanent, glued welded, glued riveted and glued threaded joints of high strength (espe cially under cyclic load), life, tightness and corrosion resis tance. The book contains basic physico mechanical and techno-logical characteristics of structural glues, recommendations on selection of glues and their use in definite composite joints. Given are also strength characteristics of various glued joints, which enable us to compare the performance of various types of joints and select their optimum production techniques. Given are brief recommendations on the design of sheet structures produced by means of glued welded, glued riveted and glued threaded joints as well as their technical and economic effectiveness. The book was written for a wide circle of technologists, designers and scientists of various industrial branches.